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BUREAU OF PUBLIC ROADS

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PARKER STREET, OMAHA, IN FEBRUARY, 1926. PAVED IN 1915 WITH 2½-INCH BRICK ON A 5-INCH CONCRETE BASE

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TABLE OF CONTENTS

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THIN BRICK PAVEMENTS STUDIED

REPORT OF ACCELERATED TRAFFIC TESTS AND FIELD STUDIES BY THE BUREAU OF PUBLIC ROADS

Reported by L. W. TELLER, Engineer of Tests, and J. T. PAULS, Associate Highway Engineer, United States Bureau of Public Roads

THERE has been manifest lately a growing belief among engineers that brick less than 4 inches in thickness may properly be used in the construction of brick pavements. Advocates of the thinner brick have contended that the 4-inch depth is unnecessary, and that brick of 3-inch thickness or even less would give equally satisfactory results, and the extensive and satisfactory use of 3½ and even 3 inch brick in some parts of the country has apparently lent support to the contention.

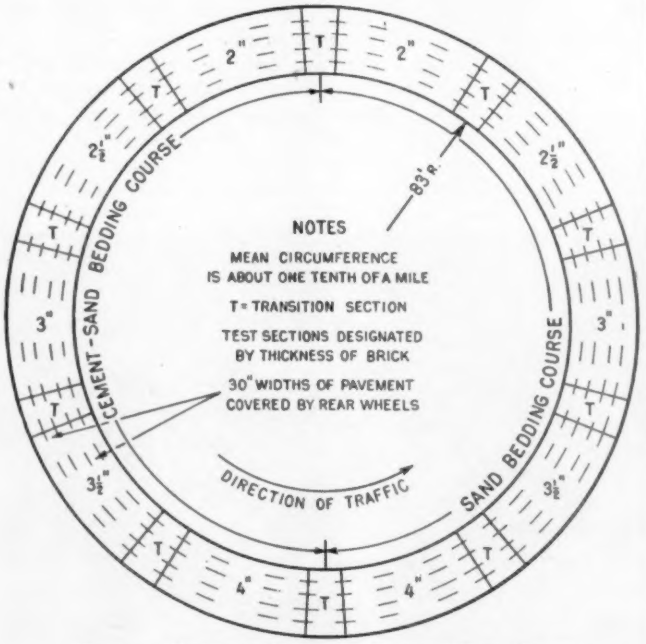


FIG. 1.—GENERAL PLAN OF BRICK TEST TRACK

If such a reduction in thickness can be made without impairing the service value of the pavement, and if the manufacture of the thinner brick is practicable, the resulting economy in the construction of brick surfaces would doubtless be very considerable; and the question is one which merits thorough investigation on that acccount. If, as experience has apparently demonstrated, the 3½ and 3 inch thickness can be employed successfully, the investigation should confirm that fact and go further to the extent of ascertaining the least thickness practicable from the points of view of manufacture, service, and cost.

Recognizing the importance of the question the Bureau of Public Roads has undertaken to conduct such an investigation, in the course of which it has made a field study of the service behavior of brick pavements in which brick of less than 4-inch thickness have been used, and concurrently an accelerated traffic test, at Arlington, Va., on sections of pavement built of brick of different thickness and a series of laboratory tests on the brick used to determine their quality. Several plants manufacturing brick of less than 3-inch thickness have also been visited to determine the attitude of the industry toward the use of the thinner brick and to ascertain if their manufacture presents any particular difficulties.

CONCLUSIONS INDICATED BY THE INVESTIGATION

The several parts of the investigation have now been completed and the analysis of the data obtained seem to warrant certain conclusions, among which the more important are:

1. That 2½-inch brick of the quality used in the Arlington traffic tests, when properly supported, will prove satisfactory for pavements carrying the heavier types of traffic.

2. That brick of 2-inch thickness, when properly supported and of the quality used in the tests, will be adequate for pavements on streets carrying the lighter types of traffic.

FIG. 2.—BRICKLAYER CLOSING IN A "DUTCHMAN." THIS FEATURE WAS NECESSARY TO COMPENSATE FOR THE CURVATURE OF THE TEST TRACK

3. That a bedding course of plain sand is more effective in reducing breakage of brick than a cement-sand bedding course, the breakage being much less on the former than the latter. The depth of the sand bedding course should not greatly exceed three-fourths inch. Increasing the depth tends to produce roughness in the pavement.

4. That cobbling of the brick is greatly increased as the spacing between bricks is increased.

5. That the use of excessive quantities of asphalt filler is a common and serious fault in construction, unnecessarily increasing the cost and resulting in a condition which impairs both the appearance and the serviceability of the pavement.

6. That base construction of other than the rigid type may in many cases prove entirely satisfactory.

Macadam bases and those constructed of certain types of natural earth appear to be suitable when the local conditions are such that these types of construction maintain their stability throughout the year.

FIG. 3.—TYPE OF TRUCK AND SOLID RUBBER TIRES USED DURING THE FIRST PHASE OF THE TEST

7. That no difference in the base construction is necessary for the different thicknesses of brick.

THE ACCELERATED TRAFFIC TESTS

The accelerated traffic tests have been carried on at the Arlington Experiment Farm, Arlington, Va., during the last several months. Their object was to obtain data on the relative resistance to heavy-truck traffic of paving brick of the several thicknesses, and every effort was made, therefore, to eliminate all other variable factors which might influence the results of the tests, the only exception being the use of the two kinds of bedding course. Because of the opportunity afforded by the test to study the relative merits of the plain sand and cement-sand bedding, it was decided to include this feature, and accordingly the pavement as laid includes duplicate sections of each thickness of brick, one on each of the two types of bedding.

In order to minimize the possibility of a variation in the quality of the brick used, they were all obtained from one manufacturer, and all are of the vertical-fiber, plain wire-cut, lugless type, 8½ inches long and 4 inches wide, the depths for the several sections being 2, 2½, 3, 3½, and 4 inches.

A circular concrete base, which formerly had served in tests of bituminous pavements, was available and was used as a base for the brick sections. This base has a mean circumference of about 540 feet, is 13 feet wide, and at the beginning of these tests was in perfect condition.

For the purpose of the brick test this circular base was divided symmetrically into 10 equal sections. On one-half of the circle the plain sand bedding course was laid to a thickness of three-fourths inch; on the other half a 1:4 cement-sand course of the same thickness was used. On each type of bedding five test sections were constructed, one of each thickness of paving brick. Each section was about 45 feet long and between them the change of one-half inch in surface elevation made necessary by the change in thickness of brick was made in a transition section about 10 feet long.

This change in elevation was accomplished by adjusting the thickness of the bedding course over a length of about 3 feet in the center of the transition section, the bedding for this distance being stiffened by the addition of a small quantity of Portland cement. The general plan of the test track and the relative position of the various sections are shown in Figure 1.

On account of the difference in circumference between the inside and outside edges of the track, it was necessary to give special attention to the manner in which the brick were laid around the circle; and it was decided that the best method would be to lay the brick in a series of short tangents and to join these tangents with "Dutchmen." One of these is shown in process of construction in Figure 2. In the track when completed there was one "Dutchman" in the center of each test section and another in each transition section; and in this way a uniform width of joints was maintained throughout the entire pavement.

After the brick were laid the pavement was rolled with a 3-ton tandem roller, and bricks which appeared to be damp were dried with a portable kerosene torch. This was followed by culling, after which the joints were filled with a squeegee coat of asphalt of 32 penetration, applied at a temperature of 375° to 400° F.

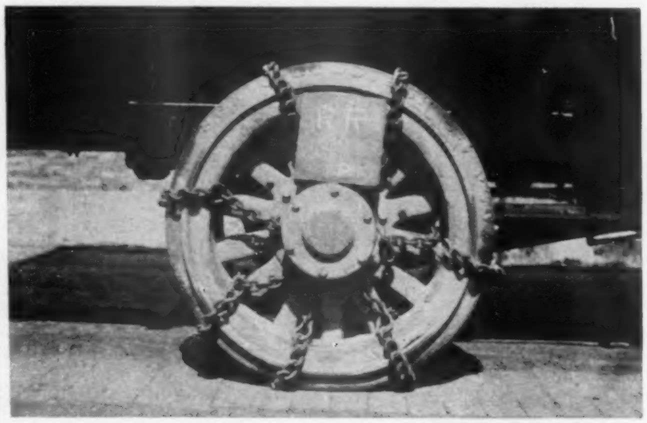


FIG. 4.—TRUCK WHEEL EQUIPPED WITH NONSKID CHAINS DURING THE SECOND PHASE OF THE TRAFFIC TEST

The pavement was constructed late in November and on account of the low temperature considerably more asphalt adhered to the surface of the pavement than was desirable. Better filling of the joints would have resulted if higher air temperatures had prevailed. A light coat of sand followed the asphalt and another rolling completed the construction of the test pavement. All work was done by a contractor thoroughly familiar with brick pavement construction.

Before traffic was applied the various sections were marked off with radial painted lines, and longitudinal traffic lines were also painted on the surface in order that the truck wheels might be confined to a path 30 inches wide and thus accelerate the test.

The general plan was to apply 3-ton, 5-ton, and 7½-ton motor-truck loads a definite number of times on each test section and to observe the results. The first phase consisted of the application of these loads with motor trucks equipped with solid rubber tires in good condition, as shown in Figure 3. In the second phase the trucks were equipped with heavy nonskid chains on the rear wheels, as shown in Figure 4. The details of the loading program for the two phases of the test are given in Table 1.

TABLE 1.—*Loading program for the two phases of the accelerated traffic test*

FIRST PHASE

Rated load	Maximum wheel load	Tire size	Load per inch of tire width	Number of trips over each test section
Tons	*Pounds*	*Inches*	*Pounds*	
3	5,800	40 by 10	580	10,000
5	7,750	40 by 12	646	10,000
7½	10,570	40 by 12	881	20,000

SECOND PHASE

Rated load	Maximum wheel load	Tire size	Load per inch of tire width	Chains: Diameter	Chains: Height above tire	Chains: Number per wheel	Number of trips over each test section
Tons	*Pounds*	*Inches*	*Pounds*	*Inch*	*Inches*		
3	5,800	40 by 10	580	½	1½	7	10,000
5	7,750	40 by 12	646	½	1½	8	10,000
7½	10,570	40 by 12	881	½	1½	8	2,200

The base of the test track was originally constructed with superelevation for a speed of 9 miles per hour. It was thought that this speed was too low for representative traffic, and during the tests without chains a speed of 12 miles per hour was maintained. This caused a difference in pressure under the two rear wheels, the effect of which will be discussed later. During the second phase of the test it was found that the trucks could not maintain a speed of over 9 miles per hour without overheating because of the heavy chains, so this speed was used throughout this part of the traffic test.

RESULTS OF THE ACCELERATED TRAFFIC TEST

The results of the accelerated traffic test as measured by the percentage of the total number of brick in the two 30-inch wheel strips of each section, broken transversely under each load in the two phases of the test, are shown in Table 2. The same data expressed in numbers of broken brick, graphically for the 2-inch brick and in tabular form for the other thicknesses, are shown in Figure 5. These are the data from the traffic test. The results of the physical tests of the brick and the compression tests made on brick taken from the pavement after the completion of the traffic tests are shown in Tables 3 and 4, respectively.

TABLE 2.—*Percentage of total number of brick in the two wheel strips of each section, broken transversely under each load*

Tire condition	Number of trips	Rated load	2-inch: Sand bed	2-inch: Cement-sand bed	2½-inch: Sand bed	2½-inch: Cement-sand bed	3-inch: Sand bed	3-inch: Cement-sand bed	3½-inch: Sand bed	3½-inch: Cement-sand bed	4-inch: Sand bed	4-inch: Cement-sand bed
		Tons	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Plain solid tires	10,000	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	10,000	5	1.6	2.1	.0	.0	.0	.0	.0	.0	.0	.0
	10,000	7½	5.6	11.8	.2	.3	.0	.0	.0	.4	.0	.2
	10,000	7½	3.5	4.6	.0	.0	.0	.0	.0	.0	.0	.0
Total			10.7	18.5	.2	.3	.0	.0	.0	.4	.0	.2
With nonskid chains	10,000	3	1.0	6.0	.0	.5	.3	.0	.0	.1	.0	.0
	10,000	5	.5	3.1	.0	.5	.0	.0	.1	.0	.0	.1
	2,200	7½	.4	1.1	.0	.0	.0	.0	.0	.0	.0	.0
Total			1.9	10.2	.0	1.0	.3	.0	.1	.1	.0	.1

TABLE 3.—*Results of physical tests on the brick used in the test pavement at Arlington Experiment Farm, Va.*

Brick thickness	Rattler loss by weight	Modulus of rupture: Tested flat	Modulus of rupture: Tested on edge	Crushing strength on edge
Inches	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
2	22.8	2,088	1,991	10,240
2½	18.8	2,461	2,197	12,530
3	19.0	2,115	1,964	10,770
3½	17.0	2,233	2,146	10,916
4	16.8	2,117	1,998	10,850

TABLE 4.—*Results of compression tests on the different sizes of brick in various conditions taken from the test pavement after the completion of all traffic*

Condition of cobbling	Brick thickness	Average crushing strength on edge (pounds per square inch): Not broken transversely	Traffic stage in which transverse break occurred[1]: A	B	C	D	E	F
	Inches							
Minimum	2	8,370	------	6,090	------	10,980	9,170	9,240
Average	2	8,490	7,550	6,260	8,290	6,740	------	9,570
Maximum	2	7,490	7,520	6,220	7,920	5,770	------	------
Minimum	2½	9,840	------	------	------	------	------	------
Average	2½	9,240	------	9,970	9,340	10,810	11,010	------
Maximum	2½	8,300	------	------	7,270	9,790	------	------
Minimum	3	10,110	------	------	------	------	------	------
Average	3	8,540	------	------	------	------	------	------
Maximum	3	8,180	------	------	------	------	------	------
Minimum	3½	9,860	------	------	------	------	------	------
Average	3½	9,810	------	------	8,150	------	9,940	------
Maximum	3½	6,200	------	------	------	10,120	------	------
Minimum	4	11,090	------	------	------	------	------	------
Average	4	9,980	------	------	9,530	------	8,630	------
Maximum	4	10,730	------	------	------	------	------	------

[1] Traffic stages.

A. Includes 10,000 trips with 3-ton load and plain solid tires (in which no breaks occurred) and 10,000 trips with 5-ton load and plain solid tires. Breaks under this traffic are indicated in the photographs by a solid circle.

B. Includes A plus 10,000 trips with 7½-ton load and plain solid tires. Breaks under this traffic are indicated in the photographs by an open circle.

C. Includes A and B plus 10,000 trips with 7½-ton load and plain solid tires Breaks under this traffic are indicated in the photographs by a triangle.

D. Includes A, B, and C plus 10,000 trips with 3-ton load and plain solid tires with nonskid chains. Breaks under this traffic are indicated in the photographs by a single line.

E. Includes A, B, C, and D plus 10,000 trips with 5-ton load and plain solid tires with nonskid chains. Breaks under this traffic are indicated in the photographs by a cross.

F. Includes A, B, C, D, and E plus 2,200 trips with 7½-ton load and plain solid tires with nonskid chains. Breaks under this traffic are indicated in the photographs by an open square.

From a study of the graphs in Figure 5 it will be seen that:

1. Practically all transverse breakage occurred in the 2-inch brick sections.
2. Within the limits of the test, resistance to breakage by the 2½-inch brick appears to have been but slightly less than that of the thicker brick.
3. Breakage in sections laid on sand bedding is less than half of that occurring in sections laid on cement-sand bedding.
4. The greatest amount of breakage occurred during the application of the 7½-ton load with plain solid tires.
5. The greatest increase in breakage occurred during the first 10,000 trips of the 7½-ton, plain-solid-tired traffic.
6. The rate of breakage greatly decreased under the traffic following completion of the 7½-ton, plain-solid-tired traffic.

The high resistance to breakage shown by the 2½-inch brick was one of the important results obtained from this test. The slightly better quality indicated by the physical tests can only partially explain

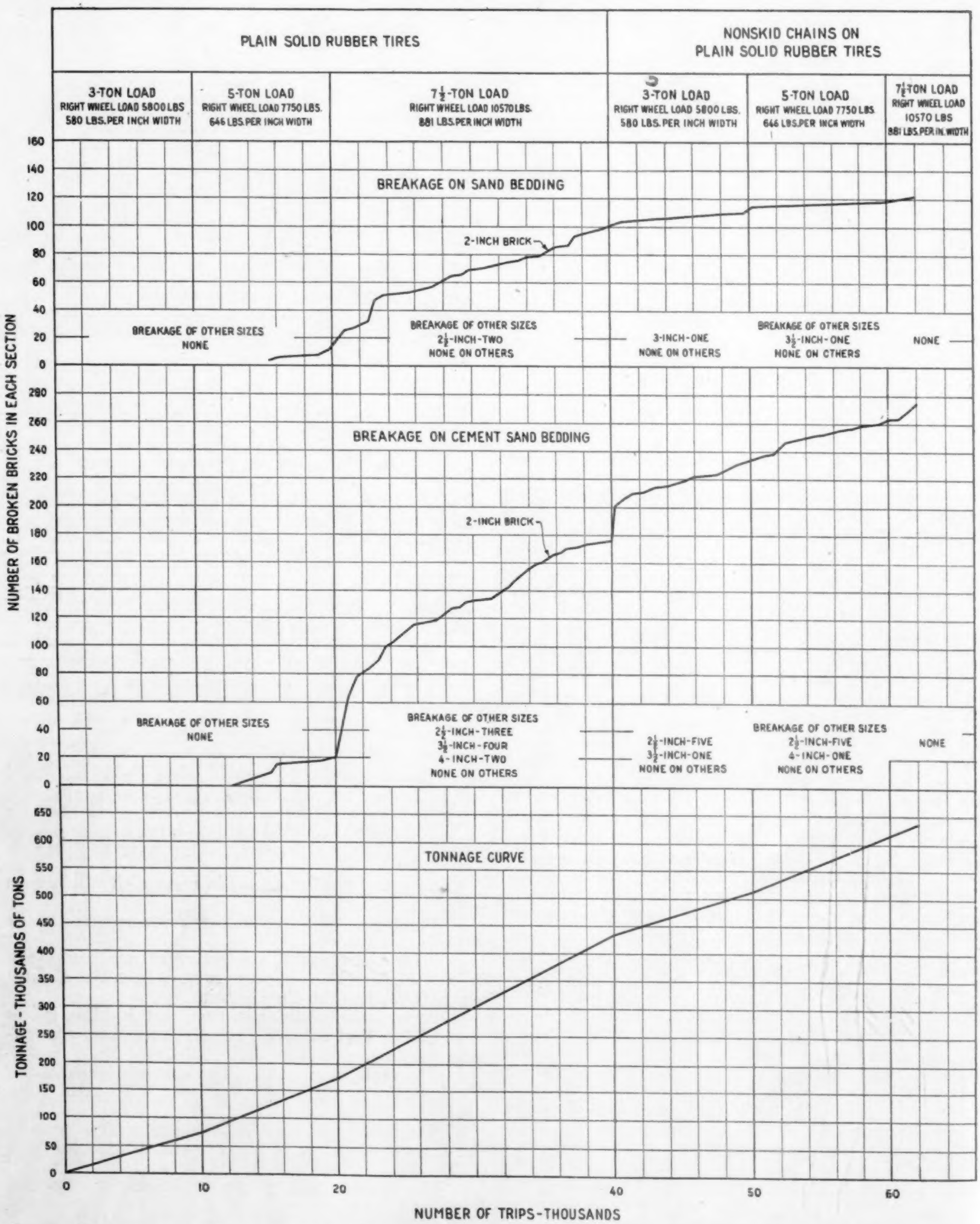


FIG. 5.—RESULTS OF THE ACCELERATED TRAFFIC TEST AS MEASURED BY THE NUMBER OF BRICK IN THE 30-INCH WHEEL STRIPS OF EACH SECTION, BROKEN TRANSVERSELY UNDER EACH LOAD IN THE TWO PHASES OF THE TEST; AND CURVE SHOWING THE TONNAGE TO WHICH THE BRICK WERE SUBJECTED

the remarkable strength of this brick under severe traffic conditions.

The marked contrast in breakage occurring on the two types of bedding course strikingly demonstrates the superiority of the plain sand over the cement-sand bedding, at least for the heavy-traffic pavements.

The higher rate of breakage which occurred during the early traffic, as shown in Table 2 and Figure 5, is probably explained by variation in the quality of the brick. It is probable that there were in each section certain brick slightly warped or of poorer grade, and these, breaking under the lighter loads, would tend to increase the early rate of breakage.

The greater breakage occurring under the outer wheels in the tests made with plain solid tires is shown by Table 5. This is the condition previously referred to and attributed to the fact that the trucks when equipped with plain solid tires were operated at a speed of 12 miles per hour whereas the pavement was superelevated for a speed of 9 miles per hour. The greater load which, under this condition, would be thrown upon the outer wheel, is doubtless the cause of the greater breakage which is shown by Table 5 to have occurred in the outer wheel strip under the plain solid-tired traffic. In the tests made with nonskid chains on the rear wheels the speed of the trucks was reduced to 9 miles per hour and it will be seen from the table that the breakage in the two wheel strips in this phase of the test was more nearly equal.

TABLE 5.—*Transverse breakage occurring in the 2-inch brick sections under the outer and inner wheels*

Tire condition	Speed	Rated load	Number of trips	Number of brick broken transversely	
				Inner wheel	Outer wheel
		Tons			
Plain solid tires	12 miles per hour	3	10,000	0	0
		5	10,000	2	34
		7½	10,000	19	149
		7½	10,000	10	63
Nonskid chains on plain solid tires.	9 miles per hour	3	10,000	45	18
		5	10,000	20	22
		7½	2,200	12	4

CONDITION OF THE TEST PAVEMENT AFTER COMPLETION OF ACCELERATED TESTS

Although the amount of transverse breakage has been taken as the criterion of the relative service of the several thicknesses of brick it must be understood that the transverse breakage alone did not materially affect the condition of the pavements. The broken portions remained in position, and under the plain-solid-tired traffic did not ravel or scale at the cracks except in the 2-inch sections. The number of brick broken during the entire test was less than the number that would ordinarily be broken during the rolling of a brick pavement.

Figures 6 to 10, inclusive, show the condition of the several brick sections at the completion of the plain-solid-tired traffic; and it will be observed that the damage in all sections was practically limited to transverse breakage. Practically all the cobbling resulted from the operation of the traffic equipped with nonskid chains, and the greater part occurred during the early stages of this traffic. It seemed that after the corners of the brick had become slightly rounded, further rounding took place very slowly. The spacing between

2-INCH BRICK ON SAND BEDDING

2-INCH BRICK ON SAND-CEMENT BEDDING

CLOSE-UP VIEW OF 2-INCH BRICK ON SAND-CEMENT BEDDING

FIG. 6.—CONDITION OF THE 2-INCH BRICK SURFACE AFTER THE COMPLETION OF THE PLAIN-SOLID-TIRED TRAFFIC. BROKEN BRICK ARE MARKED WITH WHITE PAINTED SYMBOLS THE SHAPE OF WHICH INDICATES THE AMOUNT OF TRAFFIC WHICH HAS PASSED OVER THE SECTION UP TO THE TIME THE BREAK OCCURRED. FOR EXPLANATION OF SYMBOLS SEE TABLE 4

the brick appeared to be a controlling factor in the amount of cobbling which took place; and brick laid

FIG. 7.—CONDITION OF THE 2½-INCH BRICK SECTION LAID ON SAND BEDDING AFTER COMPLETION OF THE PLAIN-SOLID-TIRED TRAFFIC

FIG. 8.—CONDITION OF THE 3-INCH BRICK SECTION AFTER COMPLETION OF THE PLAIN-SOLID-TIRED TRAFFIC. THERE WAS NO APPARENT DIFFERENCE BETWEEN THE SECTIONS ON SAND AND CEMENT-SAND BEDDING COURSES

FIG. 9.—CONDITION OF THE 3½-INCH BRICK SECTION AFTER COMPLETION OF THE PLAIN-SOLID-TIRED TRAFFIC. THERE WAS NO APPARENT DIFFERENCE IN THE SECTIONS LAID ON THE TWO BEDDING COURSES

FIG. 10.—CONDITION OF THE 4-INCH BRICK SECTION. IN THIS CASE ALSO THERE WAS NO APPARENT DIFFERENCE BETWEEN THE SECTIONS ON THE TWO BEDDING COURSES

with a wide spacing consistently showed greater cobbling. Edges of the cracks formed in broken bricks were rounded about the same amount as the original edges of the brick.

The condition of the brick in the several sections after the completion of the chain-equipped traffic is shown in Figures 11, 12, and 13. It will be noted that very little difference is apparent between the condition of the 2½, 3, 3½, and 4 inch brick sections, all being in almost perfect condition at the completion of the traffic test. The sections of 2-inch brick, on the other hand, show marked effects of the heavy traffic.

TEST TRAFFIC COMPARED WITH TRAFFIC ON ACTUAL HIGHWAYS

It will be seen from the tonnage curve in Figure 5 that a total of 62,200 trucks passed over the 30-inch strips of the test pavements, that about one-third of these were equipped with the heavy nonskid chains, and that the total tonnage moved during the period of the test amounted to approximately 630,000 tons.

A quantitative comparison of the traffic applied to the test sections with the actual traffic using a few heavy-traffic highways is made possible by the studies previously made by the Bureau of Public Roads of the transverse distribution of truck traffic on paved highways of various widths.[1] Using the data from these studies it is possible to estimate the maximum concentration of actual traffic on a strip of any given width in terms of a percentage of the total traffic. Applying these percentages to the known traffic on certain heavily traveled highways it is possible to approximate the maximum amount of traffic passing over a strip of these highways 2½ feet wide corresponding to the width of the traffic lanes on the test track.

For purposes of comparison in this manner certain highways in Cook County, Ill., have been selected. According to the survey of traffic on the highways of the county made by the Bureau of Public Roads and local authorities,[2] the truck traffic on these highways, shown in Table 6, is the heaviest to be found on any highways in the county. It is interesting to note,

[1] Transverse Distribution of Motor Vehicle Traffic on Paved Highways, by J. T. Pauls, PUBLIC ROADS, vol. 6, No. 1, March, 1925.

[2] Highway Traffic and the Highway System of Cook County, Ill., by the Bureau of Public Roads and the Cook County Highway Department.

therefore, that the traffic of trucks of the several capacities applied to the test track is equivalent to the corresponding traffic over these highways in periods of from 2 to 146 years, as shown by Table 7. In terms of total tonnage the test traffic is equivalent to five years of traffic on the most heavily traveled of these important motor truck arteries.

TABLE 6.—*Daily loaded truck traffic on several highways in Cook County, Ill., 1925*

Name of highway	Width of pavement	Capacity of trucks						Total tonnage
		3 to 4 tons		5 to 5½ tons		6 to 7½ tons		
		No.	Tonnage	No.	Tonnage	No.	Tonnage	
	Feet							
Waukegan Road	18	19	143	18	190	8	120	450
Do	18	20	150	57	599	3	45	794
Lincoln Avenue	18	14	105	23	242	9	135	482
Dempster Street	18	3	23	6	63	1	15	101
Halsted Street	18	32	240	35	368	1	15	623
Ogden Avenue	24	76	570	29	305	3	45	920

TABLE 7.—*Length of time required for selected pavements in Cook County, Ill., to carry on two 30-inch strips, traffic in number of vehicles and tonnage equivalent to that applied to the test pavement*

Name of highway	Capacity of trucks						By total tonnage
	3 to 4 tons		5 to 5½ tons		6 to 7½ tons		
	By trips	By tonnage	By trips	By tonnage	By trips	By tonnage	
	Years	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*
Waukegan Road	7	7	7	7	18	18	9
Waukegan Road	7	7	2	2	48	48	5
Lincoln Avenue	9	9	6	6	16	16	9
Dempster Street	44	44	22	22	146	146	45
Halsted Street	4	4	4	4	146	146	7
Ogden Avenue	2	2	5	5	57	57	5

In the above evaluation of the traffic applied to the test sections only a few of the most important truck-carrying highways were used for comparison. A more equitable comparison would probably be obtained were we to use the average of the truck traffic on the Cook County highway system. Compared in this way the traffic on the test sections is shown by Table 8 to be equivalent to the average traffic using all highways in the county in 18 years, and the test traffic of 6 to 7½ ton trucks to be equivalent to the corresponding actual in 70 years.

TABLE 8.—*Average trips and tonnage of the several sizes of trucks passing over the highways of Cook County, Ill., and the time value of the test traffic, based on an 18-foot two-way pavement*

Capacity of trucks	Average truck traffic on Cook County highways		Duration of actual traffic equivalent to that on test sections
	Trucks per day	Approximate tonnage	
			Years
3 to 4 tons	16	121	8
5 to 5½ tons	9	95	14
6 to 7½ tons	2	30	70
All capacities	27	246	18

Both the plain-tired and the nonskid-chain-equipped traffic applied to the test pavement was used in making the comparison shown in Tables 7 and 8. To obtain a comparison of that portion of the test traffic equipped with chains with similar traffic on actual highways, it is necessary to make an estimate of the portion of the year during which such traffic passes over the highways. It is believed that by estimating the yearly duration of this type of traffic at two months, ample time is allowed to cover the most severe conditions. On this or any other reasonable basis of comparison it will readily be seen that the test traffic with chains was far greater than any that could possibly come on any actual highway during the life of the pavement.

THE RESULTS OF THE PHYSICAL TESTS OF THE BRICK

The quality of the brick used in the several test sections is shown by the results of the physical tests recorded in Table 3. These tests indicate that the brick used in the test pavement were of about average quality, though some difference appears to exist in the quality of the different sizes.

Rated according to their moduli of rupture and crushing strength the test results indicate the order in quality of the different sizes to be as follows: 2½-inch (best); 3½-inch; 4-inch; 3-inch; 2-inch (poorest).

The rattler losses, on their face, indicate a different order; but it has long been recognized that for brick of equal quality but different in size, the comparative rattler losses are not directly proportional to the differences in weight. Engineers have recognized the injustice of specifying the same percentage of wear for different thicknesses, and have adopted, very generally, the practice of allowing some tolerance for the thinner brick in comparing their rattler loss with that specified for the thicker brick.

It is apparent that the loss in the brick undergoing the rattler test is more nearly a function of the total length of edge than of the weight of the brick. In view of the increasing use of the thinner brick, it would seem, therefore, that some modification in the standard rattler test should be made so as to make it applicable to sizes of brick differing from that of the original standard block. Until such a modification is adopted, however, it will be necessary to correct the observed losses for the various sizes of brick so as to convert them to a comparable basis.

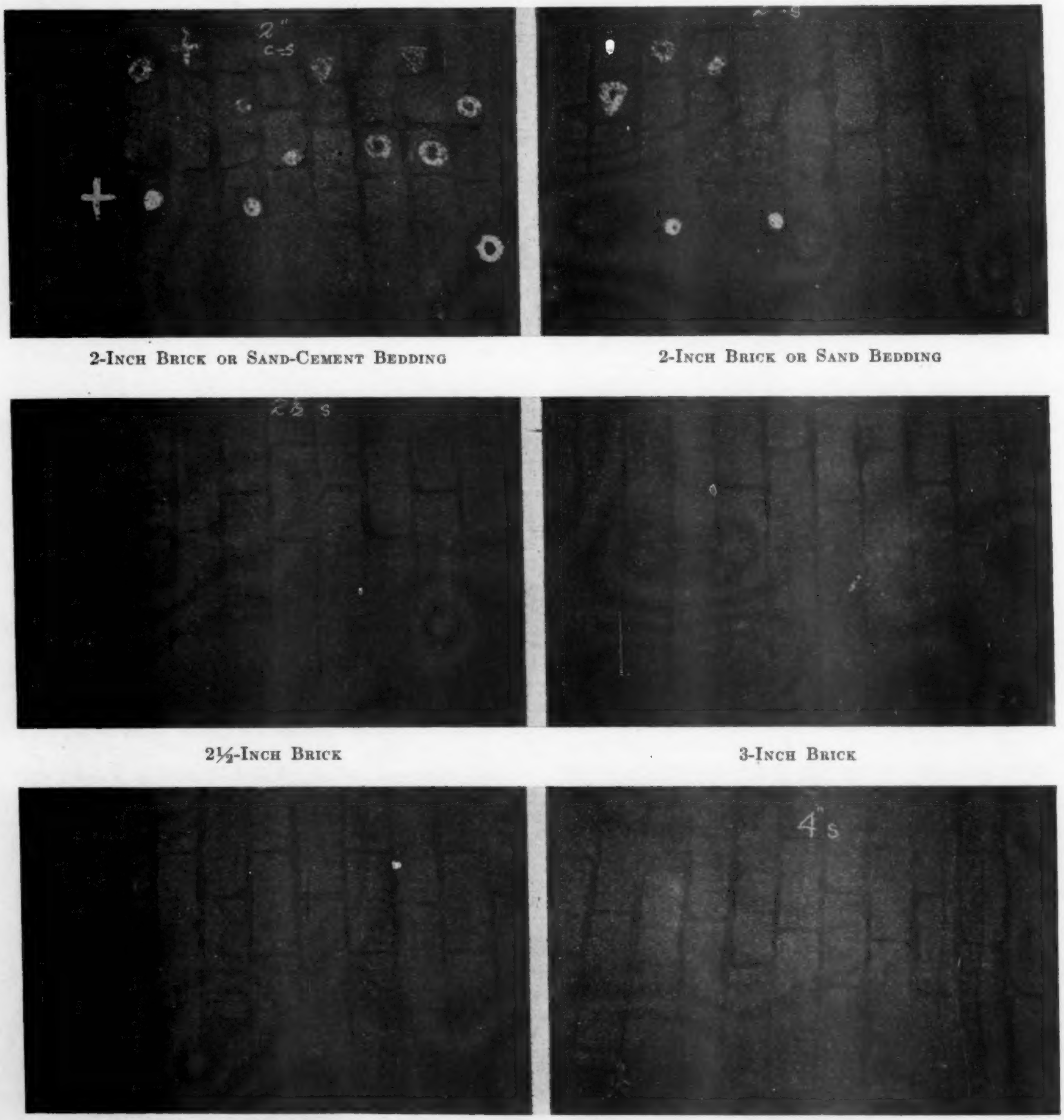
Applying the corrections recently suggested by the Bureau of Public Roads,[3] to the rattler losses of the various sizes as shown in Table 3, the order of quality of the different sizes of brick used in these tests is brought into conformity with that indicated by the modulus of rupture and crushing strength tests.

The results of the compression test made on the brick taken from the test pavement after the completion of all traffic are given in Table 4. In making this test it was hoped to correlate the result of this test with service behavior. Comparing the crushing strength of the different brick with their condition after the test, it will be noted generally that good conditions both as to rounding and breakage were characteristic of the bricks giving the higher crushing results, while broken or badly rounded brick gave consistently lower values.

A striking point noticed in the data from the compression tests on the brick which had carried traffic was the consistently lower value obtained from this test as

[3] Effect of Size of Brick on Rattler Loss, by F. H. Jackson, PUBLIC ROADS, vol. 7, No. 5, July, 1926.

compared with the result of the same test on brick that had not been subjected to the heavy test traffic. It was first thought that this might be an indication of fatigue in those brick which had carried the heavy did not agree with those obtained in the former series of tests. It appeared that the difficulty might be, and probably was, due to the failure of the capping on the worn brick. Accordingly transverse bending



2-Inch Brick on Sand-Cement Bedding

2-Inch Brick on Sand Bedding

2½-Inch Brick

3-Inch Brick

3½-Inch Brick

4-Inch Brick

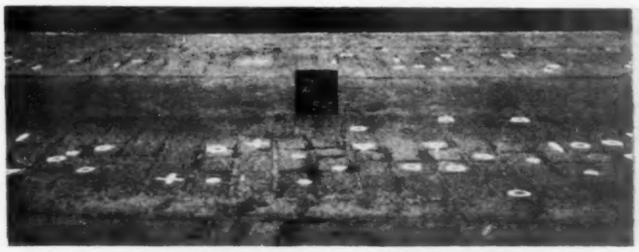
Fig. 11.—Looking Down on the Several Sections After Completion of the Chain-Equipped Traffic. None but the 2-Inch Brick Showed Sufficient Breakage to Justify a Conclusion as to the Effect of the Type of Bedding. For Explanation of Symbols see Table 4

continuous traffic of the test. In order to obtain more data on this point additional tests were made. At first, a series of check compression tests was run. These test data, although consistent in themselves, tests were run on brick which had carried traffic and on those which had not and these results did not show the reduction in strength indicated by the compression tests.

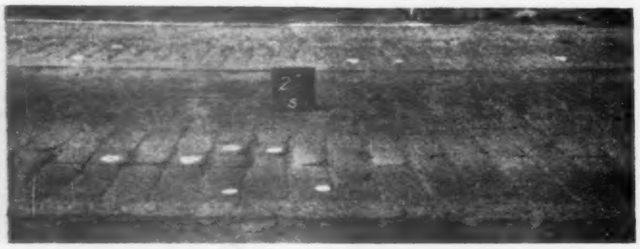
THE FIELD SURVEY

By making a condition survey of thin-brick pavements in actual service, and by obtaining information from local engineers and highway officials regarding

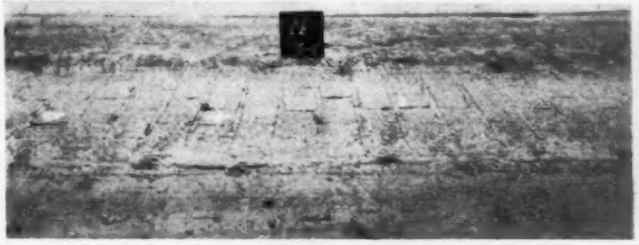
Pavements in which brick less than 3 inches in depth have been in service for a considerable length of time are practically limited to portions of Texas, Louisiana, Oklahoma, and Nebraska. The field survey was thus,



2-Inch Brick on Sand-Cement Bedding



2-Inch Brick on Sand Bedding

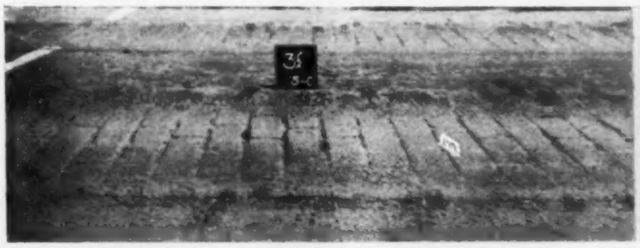


2½-Inch Brick on Sand-Cement Bedding

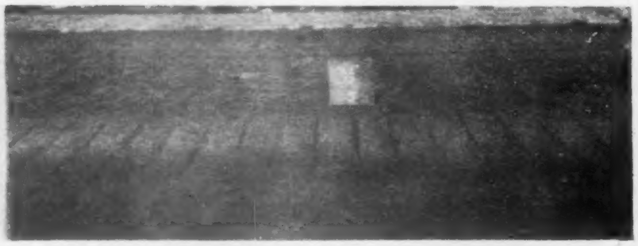
2½-Inch Brick on Sand Bedding

3-Inch Brick on Sand-Cement Bedding

3-Inch Brick on Sand Bedding



3½-Inch Brick on Sand-Cement Bedding



3½-Inch Brick on Sand Bedding

4-Inch Brick on Sand-Cement Bedding

4-Inch Brick on Sand Bedding

Fig. 12.—Looking Across the Several Sections After Completion of the Chain-Tired Traffic, Showing the Breakage and Degree of Cobbling

such factors as construction, age, climatic conditions, traffic, and maintenance, it has been possible to arrive at some conclusion as to the merits of the thinner paving brick in actual service.

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of necessity, confined to this section. Every effort was made to obtain, through consultation with local engineers and highway officials, accurate information regarding all conditions which might influence the

behavior of each pavement, and also their views as to the adequacy of the particular pavement to meet the traffic requirements.

Special attention was paid to the effect of the first attempt at using thinner brick on the subsequent policy with regard to brick thickness, using this criterion as a measure of the sufficiency of the design. The first thin brick pavement laid in a community in many cases can be classed as an experiment but similar construction later may be taken as an expression of the satisfaction of the community with the type of construction.

FIG. 13.—BRICK OF THE DIFFERENT SIZES TAKEN FROM THE TEST PAVEMENT AFTER TRAFFIC. THE GROUP SHOWS THE EXTREME VARIATIONS IN THE CONDITION OF THE BRICK AFTER THE SERVICE TESTS

This survey involved a detailed inspection of the condition of several million square yards of pavements in which brick of 2½ and 2¼ inch thickness were used. Data on age, type of construction, type of traffic, maintenance, and other influencing factors were obtained for each pavement inspected.

OBSERVATIONS MADE DURING THE FIELD STUDY

The following paragraphs give condensed information with regard to the condition of the brick pavements inspected which were built with brick under 3 inches in thickness. The condition reported is that which existed in February, 1926.

Greenville, Tex.—Located in the black waxy soil area, an unusually bad subgrade condition. This was the first city to lay brick flat, and to use bricks of 2¼-inch thickness.

Approximately 12,000 square yards of 2¼-inch repressed brick was laid on Main Street during 1905–06. The brick were laid on a 5-inch pit-run-gravel concrete base, and 1½-inch sand cushion with a filler of 1:2 grout.

This pavement has had heavy traffic, a large amount of which has been in steel-tired vehicles. Very little breaking, rounding, or cobbling has taken place, the pavement being in excellent condition except at a few places where breaks in the base have occurred (fig. 14).

Approximately 90,000 square yards of brick pavement was laid during 1914, using 2½-inch wire-cut, vertical-fiber brick. The construction consisted of a 4-inch concrete (1:7 pit-run gravel) base, 1½-inch sand bedding, and asphalt filler (penetration 57).

These pavements were in nearly perfect condition although they had received no maintenance except at a few locations where failures in the base, brought on by the unusual, unstable subgrade, had occurred.

Sulphur Springs, Tex.—Better subgrade conditions than at Greenville. Paved streets carry traffic occasioned by surrounding rich agricultural area (fig. 15).

Approximately 60,000 square yards of 2½-inch brick were laid on Main Street and Square during 1915. The construction was 4-inch concrete (1:7 pit-run gravel) base, 1-inch sand bedding, and asphalt filler (penetration 57).

The condition of these pavements was nearly perfect; very few brick had broken and very little cobbling had taken place. They had received no maintenance except on a short portion of Main Street where additional asphalt filler had been recently applied.

Connolly Street paved with 3-inch brick during 1915 appeared to be in no better condition than the 2½-inch brick laid during the same year.

Tyler, Tex.—This city is located in the iron-ore belt. The soil should make a very stable subgrade for any type of pavement. The traffic on some of the strreets is fairly heavy.

A considerable number of 3-inch brick were laid during 1920 on a natural soil base and some on old water-bound macadam surface. Both types of pavement were in nearly perfect condition, although they had had no maintenance prior to the date of inspection.

FIG. 14.—MAIN STREET, GREENVILLE, TEX. DETAIL VIEW OF THE 2¼-INCH REPRESSED BRICK SURFACE LAID 1905–06

When the inspections were being made 140,000 square yards of 2½-inch brick pavement was being laid on several streets of the city, the new pavements being laid on 4-inch concrete (1:6 pit-run gravel) base, with a 1-inch sand bedding and asphalt filler.

The Cotton Belt Railroad has built 2½-inch brick pavements on 6-inch concrete base along the unloading tracks in its freight yards.

Temple, Tex.—This city is in the black waxy soil area. The surrounding country is a rich, agricultural district and traffic on many of the city streets is heavy.

Approximately 40,000 square yards of 2½-inch brick were laid on Main and other streets during 1915. The construction was as follows: 4 to 5 inches of concrete (1:8 pit-run gravel) base, 1-inch sand bedding and asphalt filler. The condition of these pavements at the time of the inspection was good, although some failures had occurred in the bases apparently from bad subgrade conditions (fig. 16).

From 1923 to 1925, 60,000 square yards of 2½-inch brick were laid, the construction being the same as in 1915, using the 4-inch concrete base on residential streets and 5 inches on business streets.

FIG. 15.—PUBLIC SQUARE, SULPHUR SPRINGS, TEX. TWO AND ONE-HALF-INCH BRICK LAID IN 1915 ON A 4-INCH CONCRETE BASE WITH 1-INCH SAND BEDDING AND ASPHALT FILLER

Prior to 1923 some of the pavements constructed were built of 3-inch brick; since then only the 2½-inch size has been used. No difference in the condition of streets paved with the 3 and 2½ inch brick was apparent at the time of the inspection.

Fort Worth, Tex.—This city is using 2½-inch brick on residential and outer business streets. The construction is 5-inch (1:3:5) concrete base, 1-inch sand bedding and asphalt filler.

Victory Boulevard was paved during 1925 with 2½-inch brick, laid on a 5-inch (1:3:5) concrete base with 1-inch (1:4 cement-sand) bedding and asphalt, filler (penetration 57). This street has a very heavy truck traffic to and from the wholesale district of the city. The condition of the pavement was nearly perfect when inspected and no ill effect of the heavy truck traffic was visible.

Okmulgee, Okla.—A great deal of oil field traffic is carried over the city streets. The old brick pavements, in particular, have been subjected to a large amount of steel-tired traffic.

From 1916 to 1923, 220,000 square yards of 2½-inch brick was laid on 4½ to 5 inch (1:3:5) concrete base, with 1½-inch sand bedding and asphalt filler. Most of these pavements were in good condition when inspected and had required no surface maintenance. The portion built during 1916 was of a local and inferior brick and it had cracked and cobbled badly.

About 30,000 square yards of 3-inch brick was laid during 1921. None of this size has been laid since.

Henryetta, Okla.—The streets in this city carry heavy traffic to and from the surrounding oil and coal fields.

During 1918, 1920, 1922, and 1923, 200,000 square yards of 2½-inch brick were laid on 5-inch (1:3:5) concrete base, with 1-inch bedding and asphalt filler. These pavements were in perfect condition and had received no surface maintenance.

About 25,000 square yards of 3-inch brick were laid during 1917. This portion had been refilled with asphalt; and no brick of this thickness had since been laid.

Wetumka, Okla.—The streets carry heavy oil and cotton traffic.

About 12,000 square yards of 3-inch brick and 50,000 square yards of 2½-inch were laid during 1924 and 1925. The construction was: 5-inch (1:3:5) concrete base, 1-inch sand bedding and asphalt filler (penetration 55). An excessive quantity of filler was used during construction and was still on the surface when inspected. Shoving and peeling of this mat will very likely cause a rough surface.

Okeemah, Okla.—The principal streets carry heavy traffic from the surrounding oil fields.

About 35,000 square yards of 2½-inch brick were laid during 1920. The construction was: 5-inch (1:3:5) concrete base, 1-inch sand bedding, grout

MAIN STREET—2½-INCH BRICK ON A 5-INCH CONCRETE BASE, 1-INCH SAND BEDDING AND ASPHALT FILLER

RESIDENTIAL STREET—2½-INCH BRICK ON A 4-INCH CONCRETE BASE, 1-INCH SAND BEDDING AND ASPHALT FILLER

FIG. 16.—CONDITION OF BRICK LAID AT TEMPLE, TEX., IN 1915 ON MAIN STREET AND A RESIDENTIAL STREET

filler on a portion of Main Street and asphalt on the other pavements. These streets were in nearly perfect condition when inspected in February 1926 (fig. 17).

Oklahoma City, Okla.—About one-half mile of 18-foot pavement was laid with 2½-inch brick during 1918. This pavement is on the main entrance to the city and carries very heavy traffic. The construction was: 4-inch (1:3:6) concrete base with monolithic 4-inch concrete curbs, 1-inch sand bedding, and asphalt filler. It was in nearly perfect condition, there being very few broken bricks and very little cobbling. It had had no surface maintenance (fig. 18).

Oklahoma County, Okla.—The county is building 5 miles of 18-foot brick pavement using 2½-inch brick on the same approach to Oklahoma City. The construction is: 5-inch (1:3:5) concrete base with 6-inch monolithic curbs. The base is being built with a floated finish, and 1-inch asphalt-filled transverse expansion joints are being put in the base about every 40 feet. A three-fourth inch thickness of sand bedding is used.

Ponca City, Okla.—Streets in this city have unusually heavy traffic because of the large oil and refining industry which centers in and around the city. The main streets are said to have greater traffic than any other city streets in Oklahoma.

Only 2½-inch brick have been used in this city, and of these about 500,000 square yards have been laid since 1919, including 50,000 square yards on Main street during 1919, 38,000 square yards during 1921 on an old 7-inch macadam surface, and 4,000 square yards on a new 7-inch macadam during 1924. All these pavements were in almost perfect condition and had had no maintenance up to the date of the inspection.

Prior to 1921 the pavements were laid on a 1:5 cement-sand mortar base. For this, in the pavements built during 1921 and later, there has been substituted a 4-inch (1:3:5) concrete base. In all pavements the bedding course has been 1 inch of sand, and the filler has been 39-penetration asphalt. These have been used with the macadam bases also. In preparing the old macadam a certain amount of shaping was necessary.

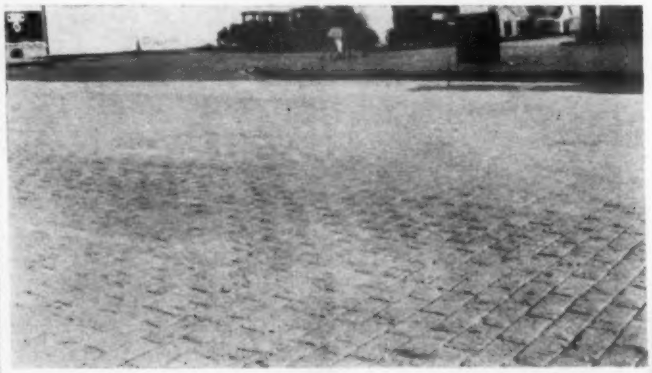

FIG. 17.—DETAIL VIEW SHOWING CONDITION IN FEBRUARY, 1926, OF THE 2½-INCH BRICK LAID AT OKEEMAH, OKLA., IN 1920 ON A 5-INCH CONCRETE BASE WITH GROUT FILLER

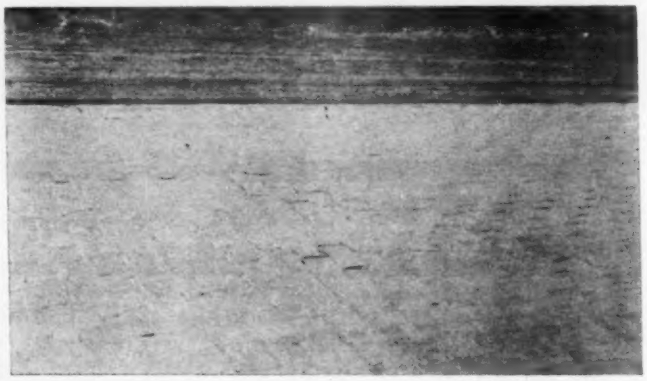

FIG. 18.—DETAIL VIEW OF THE CONDITION IN FEBRUARY, 1926, OF THE 2½-INCH BRICK LAID ON THE MAIN APPROACH TO OKLAHOMA CITY. THE BRICK WERE LAID IN 1918 ON A 4-INCH (1:3:6) CONCRETE BASE AND 1½-INCH SAND BEDDING WITH ASPHALT FILLER

Tonkawa, Okla.—This city is in the oil-field area and the principal streets have very heavy traffic. About 35,000 square yards of 2½-inch brick were laid during 1919 on Main Street and about 75,000 square yards of the same size were laid during 1922 and 1924. The portion built during 1919 was laid on a 4-inch (1:4 cement-sand mortar) base, with 1½-inch sand bedding and 1:3 grout filler. Asphalt was used as a filler in the later work. Expansion joints were placed in the surface every 20 to 30 feet. No difference in the condition of the grout-filled and asphalt-filled surfaces was apparent (fig. 19).

Blackwell, Okla.—There is heavy traffic on all the principal streets.

About 1½ miles south of the city on the main highway north and south, 1,000 linear feet of 18-foot frozen concrete pavement was surfaced with 2½-inch brick during 1920. This surface is in perfect condition.

Two hundred thousand square yards of the same size brick were laid during 1914, the construction being 4-inch (1:5 cement-sand mortar) base, 1-inch sand bedding and cement-grout filler. Transverse expansion joints were put in the grout-filled surface every 40 feet.

During and since 1922, 125,000 square yards of 2½-inch brick have been laid, and in this construction asphalt (penetration 39) has been used in place of grout as a filler.

All these surfaces were in excellent condition when inspected, very few broken brick being noted.

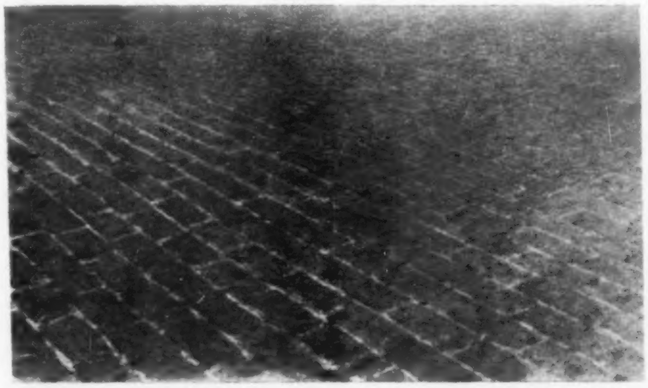

FIG. 19.—DETAIL VIEW OF 2½-INCH BRICK LAID DURING 1919 ON MAIN STREET, TONKAWA, OKLA. THE PHOTOGRAPH SHOWS THE CONDITION OF THIS PAVEMENT IN FEBRUARY, 1926. IT WAS LAID ON A 4-INCH MORTAR (1:4) BASE AND 1½-INCH SAND BEDDING WITH GROUT FILLER

Texarkana, Tex.—Approximately 30,000 square yards of 2¼-inch brick were laid on the important streets during 1922. The construction was 6-inch concrete base, ¾-inch sand bedding and asphalt filler of penetration ranging from 54 to 45. An excessive quantity of filler was applied on practically all of this construction, the asphalt mat on many streets having a thickness of as much as one-half inch. Some peeling and shoving of this material has occurred in places, and further difficulties arising from this condition may be expected to occur for a long time.

A large number of 3-inch brick have been laid on 6 and 7 inch compacted gravel base. A thick mat of asphalt filler similar to that found on the thin brick pavement covered the surface at the time of inspection and similar peeling and shoving were observed.

All the brick pavements in this city have been laid during the last four years. At the time of this inspection there was nothing to indicate that the thinner brick was giving any less satisfactory service than the 3-inch type.

Omaha, Nebr.—This city laid 2½-inch brick on Parker Street during 1915. The construction was: 5-inch (1:3:6) concrete base, 1½-inch sand bedding and asphalt filler.

This street carries residential traffic. The surface was found to be in excellent condition, very few breaks and very little rounding having taken place. The only maintenance required prior to the inspection was occasioned by three blow-ups occurring in the base.

THE INDICATIONS OF THE FIELD STUDY SUMMARIZED

A steady growth in the use of brick of less than 3-inch depth is shown by the field survey. Numerous communities were found which have adopted the thinner brick for use on some or all of their streets. Although the earlier work may be classed as experimental, as indicated by the small quantities put down and by the type of street selected for paving, subsequent paving with the thin brick in larger quantities and on streets carrying heavier traffic may well be taken as an expression of the satisfaction of the community with pavements of this type.

Table 9 shows a summary of data from some of the cities covered by the field survey in which brick of less than 3-inch thickness are used almost exclusively, which indicate these tendencies.

The pavements built with 2½-inch brick, in most cases, were in good condition. In a few localities failures had occurred in the base causing displacement in the brick. It was particularly noted that in such cases displacement in the brick had taken place without breakage. This was found to be true also for the brick over transverse and longitudinal cracks. Extreme cases of base failures with effect on the brick are shown in Figures 20 and 21.

In general, the brick surfaces were found to have had very little maintenance, except at places where failure had occurred in the base. A portion of the brick pavement laid on Main Street, Henryetta, Okla., during 1917, was refilled with asphalt during 1925, as the original filler had been largely carried away by traffic. Oklahoma enforces the five-year maintenance

FIG. 20.—CONDITION OF 2½-INCH BRICK SURFACE LAID AT GREENVILLE, TEX., IN 1914, AS IT APPEARED IN FEBRUARY, 1926. DISPLACEMENT OF THE BRICK HAS OCCURRED OVER A BASE FAILURE WITHOUT BREAKING THE BRICK

clause on new paving work, yet the larger paving contractors declared, without exception, that no allowance is made or need be made in the estimated cost of a paving job to cover a difference between maintenance costs of 2½-inch and 3-inch brick.

It was found that excessive quantities of asphalt filler had been used in many sections of brick pavement. In one locality the excess covered the brick with a thickness of as much as one-half inch. Pavements where an excess of asphalt had been used were very rough, and will probably continue to be unsatisfactory for a long time. The importance of limiting the quantity of asphalt filler to that required to fill the space between the brick was strikingly illustrated by the unsatisfactory condition of such pavements, a typical example of which is shown in Figure 22.

Table 9.—*Summary of data of the field survey*

Location	Thickness of brick	Type of brick	Area laid	Year laid	Character of streets paved	Remarks
	Inches		*Sq. yds.*			
Greenville, Tex.	2¼	Repressed.	12,000	1905–06	Main	First brick to be laid flat.
Do	2½	Wire-cut vertical fiber.	90,000	1914	Main and residential.	No 3-inch brick laid.
Sulphur Springs, Tex.	2½	do	60,000	1915	do	
Do	3	do	(1)	1915	do	No 3-inch brick laid since.
Tyler, Tex	3	do	40,000	1920	do	Do.
Do	2½	do	140,000	1925	do	
Temple, Tex	3	do	(1)	Before 1923	do	Do.
Do	2½	do	100,000	1915–1925	do	
Okmulgee, Okla	2½	do	220,000	1916–1923	do	
Do	3	do	30,000	Before 1921	do	Do.
Henryetta, Okla	3	do	25,000	1917	Main	Do.
Do	2½	do	200,000	1917–1923	Main and residential.	
Wetumka, Okla.	3	do	12,000	1924–25	Main	
Do	2½	do	50,000	1924–25	Residential.	
Okeemah, Okla.	2½	do	35,000	1920	Main and residential.	No 3-inch brick laid.
Ponca, Okla	2½	do	500,000	1919–1925	do	Do.
Tonkawa, Okla	2½	do	110,000	1919–1923	do	Do.
Blackwell, Okla	2½	do	325,000	1913–14	do	Do.

[1] Not known.

Fig. 21.—The Base Failure Shown in this Photograph is on a Residential Street of Temple, Tex. The Brick Were Laid in 1915 on a 4-Inch Concrete Base. This Pavement is in the Black Waxy Soil Area. Note that Displacement of the Brick has Occurred Without Breakage

Some changes in the construction features of brick pavements have occurred since the earlier pavements were laid. The bedding course of the early surfaces was found to range in thickness from 1½ to 2 inches laid on a rough base. Later construction shows, generally, that a ¾-inch bedding has been used on a smoothly finished base. In a few localities very fine sand had been used for bedding, but, because this type of sand shows a tendency to work up between the brick and because of loss through cracks in the base, coarser sand has been substituted as being more satisfactory.

The field survey showed that, in general, brick laid on a thin bedding course with a smoothly finished base maintained a smoother surface than those laid with a greater depth of sand on a roughly finished base.

The research of the last few years has proved that the destructive effect of motor-truck impact is greatly reduced by the construction of smooth pavement surfaces. The continued perfect alignment of the finished brick surface is dependent to a large degree, particularly on heavy traffic thoroughfares, on the smoothness with which the base course is finished and the resulting uniformity of thickness and compaction of the bedding course. Any slight increase in the construction cost for the purpose of obtaining this condition will be more than justified by the potential increase in the life of the pavement.

Fig. 22.—The Importance of Limiting the Quantity of Asphalt Filler to that Required to Fill the Spaces Between the Brick is Illustrated by the Condition of this 2¼-Inch Brick Pavement in Texarkana, Tex. The Pavement was Laid in 1922

Cement-sand grout filler was found to have been used in the construction of some of the earlier brick pavements. Some of these were built with expansion joints in the brick surface, but in the majority of cases the joints have been omitted. The need for expansion joints with this type of filler was evidenced by the scaling in the surface of the brick on many of the pavements in which no expansion joints had been provided in the surface.

A wide range in the type and construction of base used was noted in the survey. Concrete ranging from 4 to 6 inches in thickness and largely of 1:3:5 proportion was found to have been used extensively in the area covered, while old and new macadam had been used satisfactorily in many instances. One city in the iron-ore belt was utilizing the iron-ore soil with entirely satisfactory results as base for brick pavements.

The successful use of these widely different types of base indicates that there is a wide range of possibilities in base construction. Any material which remains stable at all times would appear to make a satisfactory base for a brick pavement. It is evident that these requirements may be met in many cases by base construction of the less rigid type. As the function of the base is primarily to support the allowed wheel loads without appreciable vertical displacement, any type of construction that will meet this condition is satisfactory. An old macadam or other type of surface that has proved stable under traffic should prove entirely satisfactory as a base for brick.

In a majority of the locations covered in the field study no distinction was found to have been made in the base construction for brick of different thickness. One exception was noted where 3-inch brick had been laid on a compacted gravel base while concrete had been used for the 2¼-inch thickness. In this case and in others where difference in the base construction had been made with the use of brick of different thickness

nothing was found in the condition of the pavements that would indicate the need for any variation in base construction for the different thicknesses of brick used.

Traffic.—A considerable number of the towns visited were located in the center of oil fields and as a result severe traffic conditions obtained on the more important streets. Formerly there was a considerable percentage of heavy steel-tired vehicles which have practically been superseded by heavy motor trucks. Although traffic records were not available for study it is believed that the traffic on the important streets of the cities visited was more severe than that on the streets of many of the larger cities.

A great deal of importance is attached, and properly so, to the views and experience of resident engineers and officials familiar with the use of brick under 3 inches in thickness. All of the officials interviewed from those sections of the country where brick of less than 3-inch thickness is being used expressed themselves as favorable to the use of the thinner brick, some with and others without limitations as to the type of street and traffic. Many maintained that 2½-inch brick would prove equally as satisfactory as the 3-inch thickness under all conditions, and others believed that the 2½-inch type should be limited to use on residential and outlying business streets.

The views of three prominent engineers who are intimately connected with the use of thin paving brick are expressed as follows:

Herman Beal, City Engineer, Omaha, Nebr.—I have completed an investigation of a pavement in the city built during 1915 with a 2½-inch surface. The following information being available:

Pavement on Parker Street between Twenty-ninth Street and Thirty-third Street, 30 feet wide, containing 5,360 square yards. Base 5 inches concrete, 1:3:6 mix. Bituminous filler.

This pavement is in excellent condition, the brick showing practically no wear and the surface, with the exception of one or two expansion bulges, being exceptionally good. The traffic on this street is what might be classed as medium, although occasionally heavy truck loads are hauled thereon.

Figure 23 is a detail view of the pavement described by Mr. Beal.

E. A. Kingsley, City Engineer, Dallas, Tex.—We have used 3-inch vertical fiber brick for a number of years, and are using in our heavy traffic industrial district this character of brick in paving some of our new work this year. Our first 3-inch vertical fiber brick was laid on Market Street during 1919. This pavement has extremely heavy downtown industrial traffic of both the rubber and steel tired type. We have no trouble from breaking or cracking under traffic of the 3-inch brick. We have found that this brick carries traffic equally as well as did the old 4-inch block laid on edge. We can discover no reason in studying the wear and service given by the 3-inch brick which would suggest to us that a 3½-inch or 4-inch brick might be better.

Dallas is perfectly satisfied with its heavy-traffic service on the 3-inch vertical fiber brick, and from experience that neighboring cities have had with the 2½-inch brick, we believe that this should be specified for the lighter traffic and residential districts.

D. Lewis, City Engineer, Fort Worth, Tex.—This city has been laying 2½ and 3 inch vertical fiber brick with asphalt filler on a cement-sand cushion laid on a concrete base. We have found this type of paving to give excellent results.

MANUFACTURE OF THIN BRICK PRACTICABLE

The manufacture of brick as thin as 2½ inches is accomplished without particular difficulty. Some loss from warping was said to have occurred when brick of this thickness was first manufactured. Later changes in the manufacturing process, particularly in the burning, have made this loss negligible at the present time. The brick manufacturers in the sections of the country where the thinner brick are being used, were found to be favorable to the manufacture of the 2½-inch type. The manufacture of brick with 2-inch thickness was believed by some to be impractical because of the loss occurring from warping during burning.

Reduction in the cost of a brick pavement built of thin brick is the result of decreased cost of such items as manufacture, transportation, handling on the job, and saving in the filler material.

Fig. 23.—Detail View of 2½-Inch Brick Laid on Parker Street, Omaha, in 1915, Described by Herman Beal. The Brick were Laid on a 5-Inch Concrete Base (1:3:6) with Bituminous Filler. The Photograph Shows the Condition of These Brick in 1926 After 11 Years Under Medium Traffic

Based on the cost of a 3-inch pavement the saving in materials and costs for each ½-inch reduction in thickness would be approximately as follows:

	Cost reduction	Material reduction
	Per cent	*Per cent*
Manufacture	10	
Freight	16	
Haulage	16	
Filler	16	10

AN INSTRUMENT FOR THE MEASUREMENT OF RELATIVE ROAD ROUGHNESS

DEVELOPED BY THE UNITED STATES BUREAU OF PUBLIC ROADS

NO ARGUMENT is needed to convince the user of our roads of the desirability of as smooth a surface as can be produced. A rough surface gives rise to effects unpleasant to the passenger and detrimental to the vehicle. Smooth surfaces mean greater mileage with less fatigue, with less damage to cargoes, and with lower operating costs for the vehicle. Thus the subject assumes a very considerable economic aspect.

The highway engineer is vitally interested in building and maintaining smooth roads because of the effects already mentioned and further on account of the direct effect of surface roughness on the life of the pavement. The research of the last few years has clearly pointed out that road roughness produces impact and impact contributes to the early deterioration of any type of road surface. So convincing has been the evidence of this fact that State highway engineers have expressed the belief that smoothness is the most important quality to be sought in road surfaces.

The general appreciation of the importance of this matter by highway engineers has created a demand for an instrument with which the roughness of a road surface may be measured. With such an instrument the engineer would find it possible to specify the quality demanded in new work and to obtain accurate data on the deterioration of the surface in time to apply proper corrective measures. To be most useful such a device should not only be accurate but should supply the information rapidly and in such form that it can be used immediately. Finally, it should be mechanically simple and reliable and so designed that it can conveniently be used on an automobile.

Several devices have been offered from various sources to meet the demand. The Bureau of Public Roads experimented with a number of designs over a period of several years and finally, in May, 1925, developed one which when then used in the vicinity of Washington, D. C., appeared to be better in several respects than other available instruments.

Subsequent use of this type of instrument over a considerable period of time in several States by a district engineer of the bureau indicates that it is entirely satisfactory for the purpose. It is, therefore, with considerable confidence in the worth of the instrument that a description is now presented.

There are a number of ways in which the roughness of road surfaces may be indicated by an instrument attached to a vehicle, but the fundamental principle upon which all of them depend is that the vertical motion imparted to the vehicle by the irregularities in the road surface bears a direct relation to the degree of roughness. In order that the effect of this motion upon the chassis of the vehicle may be minimized, body springs and rubber tires are provided, the deflection of which absorbs much of the undesirable vibration. The magnitude of these deflections depends not only on the magnitude of the road roughness but also on the speed of the vehicle, amount and distribution of the load, and the type and condition of the spring and tire equipment. By maintaining constant all of these other conditions, the deflection of the body springs may be made to measure the relative roughness of the riding surfaces over which the vehicle is driven. This fact furnishes the principle on which the relative roughness determinator or roughometer, as it has been called, operates.

THE RELATIVE ROUGHNESS DETERMINATOR

Briefly, the roughometer consists of a rack which is attached in a vertical position to the front axle of the vehicle. Meshed with this rack is a spur gear which is supported by the frame of the car. Movement of the front axle with respect to the chassis, caused by deflection of the body springs, thus produces translation of the rack and rotation of the gear. This gear is connected through a flexible shaft to a mechanical counter on the instrument board of the automobile. Deflection

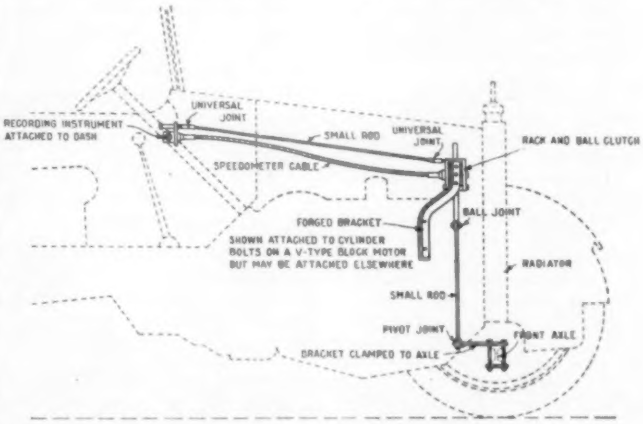

FIG. 1.—DIAGRAM OF THE RELATIVE ROUGHNESS DETERMINATOR MOUNTED ON AN AUTOMOBILE

of the front springs of the vehicle thus causes the rotation of the spindle of the counter. In order that this spindle will not rotate in the reverse direction when the body springs return from their deflected position a ball clutch is interposed between the gear mentioned and the flexible shaft which operates the counter. This ball clutch allows the flexible shaft to turn in only one direction so that the counter operates only during deflection of the body springs and thus records the summation of these deflections during the time the instrument is in operation.

Before proceeding to a detailed description of the instrument it may be desirable to call attention to certain of its distinctive features, which are:

1. It can be attached to any automobile without impairing the appearance or the normal operation of the vehicle.
2. The data are presented as abstract numerical factors which can be used immediately.
3. Satisfactorily accurate data can be obtained at normal highway operating speeds so that there is no interference with or from traffic.
4. The instrument can be thrown completely out of operation when not in use, thus preventing excessive wear of its moving parts.

DETAILED DESCRIPTION OF THE INSTRUMENT

Referring to Figure 1, which shows how the instrument is mounted on an automobile, it will be seen that it consists of two distinct parts; that is, the rack and ball-clutch mechanism which is mounted on the engine block or chassis of the car, and the recording mechanism which is permanently mounted on the instrument dash. Figure 2 shows these two parts complete but not mounted on the automobile.

In Figure 3, which is a detailed drawing of the entire mechanism, *A* is a plan of the instrument, looking down, with the rack and ball-clutch mechanism at the left and the recording mechanism at the right; *B* is a sectional view of *A*, the section being taken along the vertical longitudinal center line of the rack and ball-clutch mechanism, through the flexible cable and through the miter gears which drive the recording mechanism; *C* shows the end or side view of the rack and ball-clutch mechanism, and when mounted this side would be next to the radiator of the automobile; *D* is the front view of the recording mechanism as secured to the dash and as it appears to the operator; *E* is a vertical cross section through the ball clutch; *F* gives details of the latch which meshes the rack and gear and is controlled by the pull-out, throw-over handle located over the recording mechanism on the base plate of the instrument. The upper view shows the latch closed (rack and gear meshed); the center view shows the latch half open; and in the lower view the latch is open (rack and gear out of mesh, and the instrument not in operation).

The following is a detailed description of the instrument, in which the various parts are referred to by numbers as shown in Figure 3:

A metal frame (1) is supported by a suitable bracket, attached by screws (2) to the engine block or some other part of the chassis. (Fig. 1.) Through this frame passes a vertical rack (3), which is attached to the front axle through a rod with flexible couplings as shown in Figure 1. Any vertical movement of the axle with respect to the chassis thus causes this rack to move up or down.

Attached to and pivoted near the bottom of the stationary frame (1) is a movable metal frame (4) which is made in two pieces to facilitate casting and is secured at the bottom with cap screws (5) and at the top with a spacer rod (6).

At the center of the movable frame (4), carried in metal bearing boxes (7), is a hardened steel shaft (8), and through the middle of this shaft is a hole for lubrication, the oil being supplied by an oil reservoir in one bearing from oil cup (9). The steel shaft (8) has made with it a ball race which is ground to the proper dimensions after the steel is hardened.

On the shaft (8) next to the ball race is a hardened steel gear (10), and fastened to this gear by six screws surrounding the ball race is the hardened steel ball-clutch housing (11). This housing carries the steel balls (13); which are held in the housing and in position against the ball race by springs (13) and small screws (14).

The hardened steel gear (10) meshes with the vertical rack (3); consequently, any vertical movement of the rack is transmitted to the gear (10) and, by virtue of the ball-clutch housing (11) being fastened to the gear (10), the movement of the rack (3) causes rotation of the ball race or rotor and the steel shaft (8). The ball clutch will lock when the rack moves upward and release when the rack moves downward, yet, unless the shaft (8) is held so as to make the ball clutch release, it will simply rock back and forth. To prevent this friction is applied to shaft (8) by a brake wheel (15) which is held to the steel shaft by a set-screw, the braking friction being applied by a steel cable (16) that is secured around the spacer rod (6) at one end and is tightened by means of a thumb-nut (17) at the other end. Thus shaft (8) moves only in one direction, that in which the ball clutch locks.

At the end of the steel shaft (8) opposite from the oil reservoir, a flexible steel speedometer cable and housing (18) is attached. This cable transmits any movement of the steel shaft (8) to the recording mechanism. The recording mechanism or instrument is attached to the dash of the automobile within reach and in clear view of the operator. It consists of a base plate (19) and a mechanical set-back counter (20) which records the movement transmitted by the speedometer cable through a pair of miter gears (21) that are covered by a housing (22). The vertical movement of the rack (3) thus appears as a numerical factor on the mechanical counter.

At the top of the recording mechanism is a pull-out, throw-over handle (23). This handle is connected to a rod (24) fitted with a universal joint at each end, and controls the latch (25). When the handle (23) is turned 180 degrees at the recording instrument (from left to right) the latch (25) is extended, freeing gear (10) from rack (3) and putting the entire instrument out of operation. The dotted lines shown in Figure 3, *C* indicates the amount of movement necessary to do this.

Figure 4 shows the instrument completely disassembled, and in this figure attention is called to the simplicity of the various parts. Figure 5 shows the rack and ball clutch mounted under the hood of an automobile. This view shows the side opposite to that shown in Figure 2, and brings out clearly the details of the friction brake on the ball clutch.

USE OF THE INSTRUMENT IN THE FIELD

The various parts of the instrument are so designed that a movement of the rack of one inch records one unit on the counter. While it is possible to calibrate

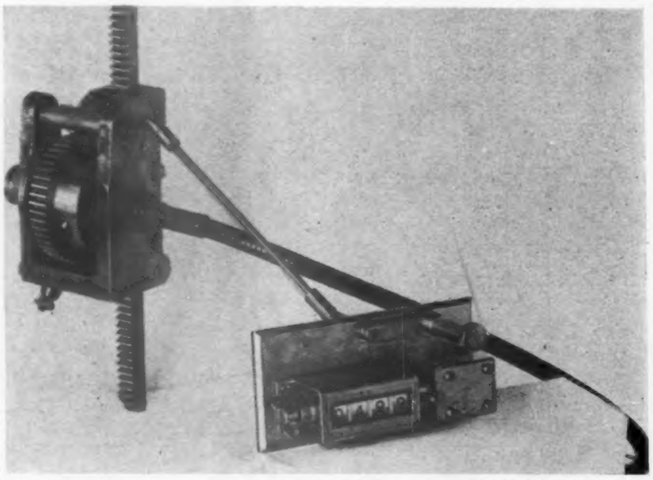

FIG. 2.—THE RACK AND BALL-CLUTCH MECHANISM AND THE RECORDING MECHANISM, COMPLETE BUT UNMOUNTED

the instrument in terms of absolute surface profile, this calibration is difficult and of no practical value. The purpose of the instrument is to indicate the relative roughness of various surfaces or the changes in roughness of the same surface over a period of time. It is only necessary, therefore, to standardize the speed, load, spring, and tire conditions of the vehicle on which it is to be used and the device will be ready for service. Care should be taken to check the tire inflation frequently and obviously the speedometer on the car should be maintained in first-class condition.

Any normal operating speed may be used; but whatever the rate decided upon it should be maintained throughout the test, and the same speed should be used in comparative tests. It is desirable, therefore, to so set the speed that it can be maintained without interfering with or interference from the other traffic on the road. Table 1 gives values obtained on a section of pavement 1½ miles in length at three speeds. This table illustrates not only the effect of speed on the magnitude of the factor obtained but also the consistency of the results obtained on several runs over the same road.

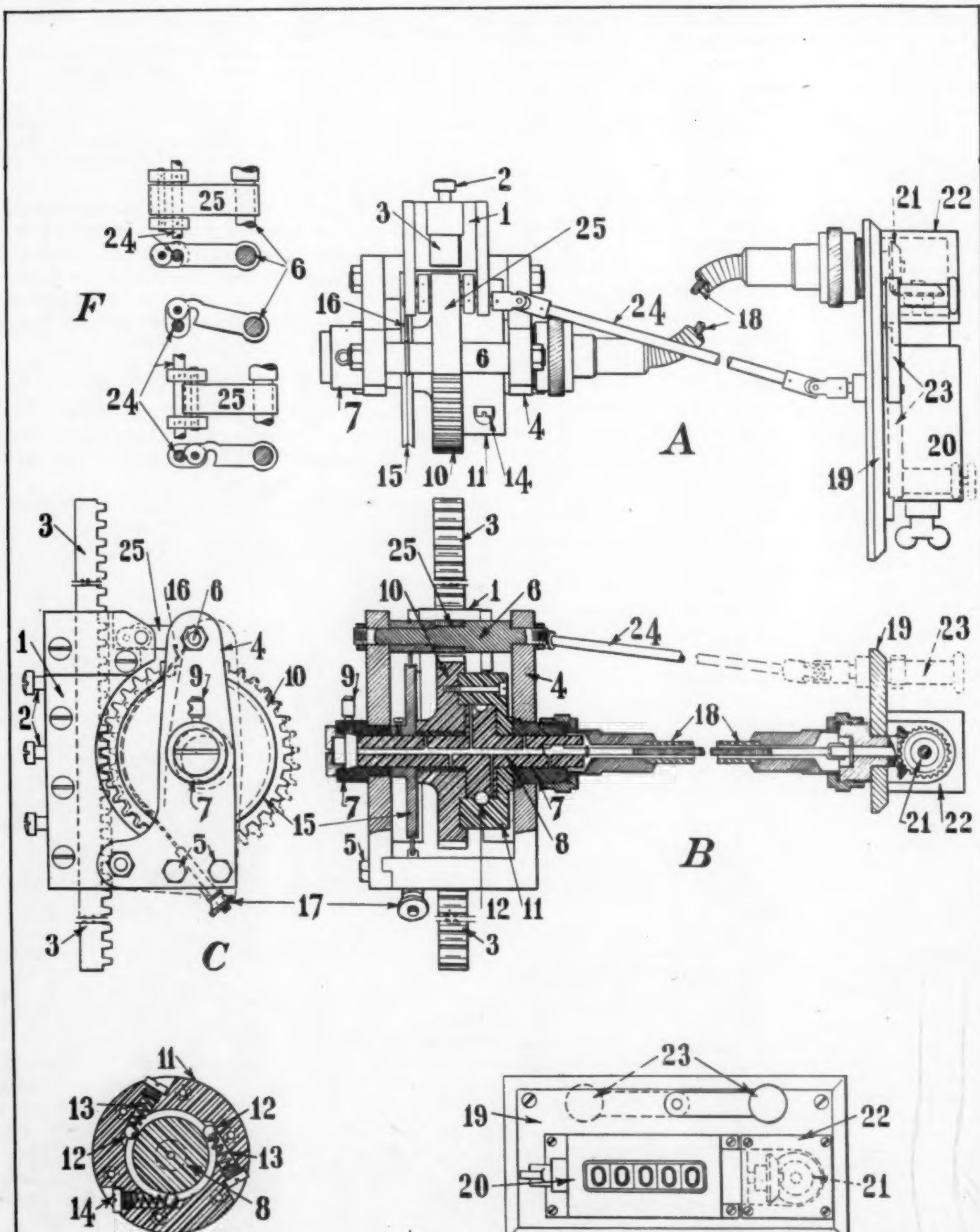

FIG. 3.—DETAILS OF THE RELATIVE ROUGHNESS DETERMINATOR

TABLE 1.—*Roughness factors obtained in operation over a section of pavement 1½ miles long*

THREE ROUND TRIPS AT 25 MILES PER HOUR			
Southbound	196	Northbound	173
Do	199	Do	168
Do	195	Do	170
Average	197	Average	170
FIVE ROUND TRIPS AT 30 MILES PER HOUR			
Southbound	225	Northbound	206
Do	224	Do	203
Do	227	Do	201
Do	230	Do	202
Do	225	Do	203
Average	226	Average	203
THREE ROUND TRIPS AT 35 MILES PER HOUR			
Southbound	242	Northbound	221
Do	242	Do	224
Do	246	Do	224
Average	243	Average	223

From these data it will be seen that the maximum deviation of any reading from the average of the group is considerably less than 2 per cent. It will also be noted that the increase in the roughness factor is a most directly proportional to the increase in speed.

The curves in Figure 6 indicate the relation between the speed of the vehicle and the magnitude of the roughness factor for two different vehicles equipped with different types of tire equipment. The parallel curves were made with the same car on the same length

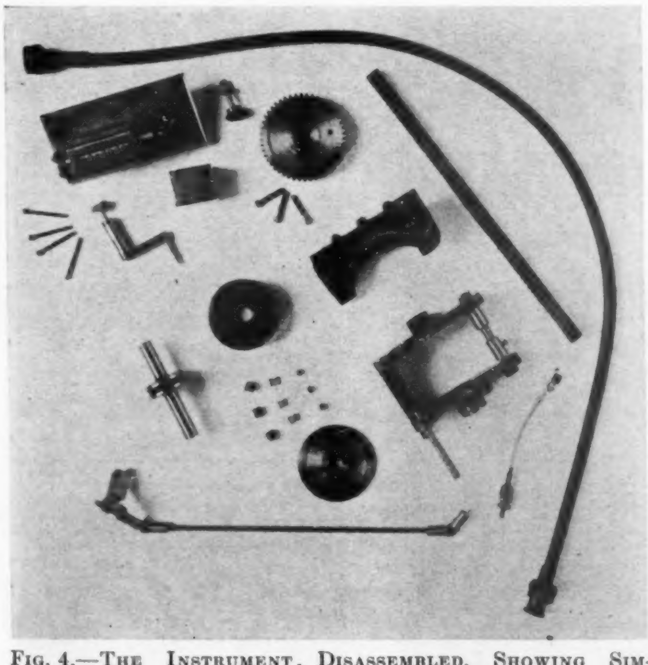

FIG. 4.—THE INSTRUMENT. DISASSEMBLED, SHOWING SIMPLICITY OF THE VARIOUS PARTS

of road but running in opposite directions. One test was made near Washington, D. C., the other near Chicago, Ill.

The significance of these curves lies in the fact that they show a definite relation between the speed of the vehicle and the magnitude of the roughness factor. This relation will not be the same for different sets of equipment and should be determined for those test conditions which have been selected as standard for the equipment used.

Figure 7 shows graphically some data which indicate the consistency of the instrument. The car was driven

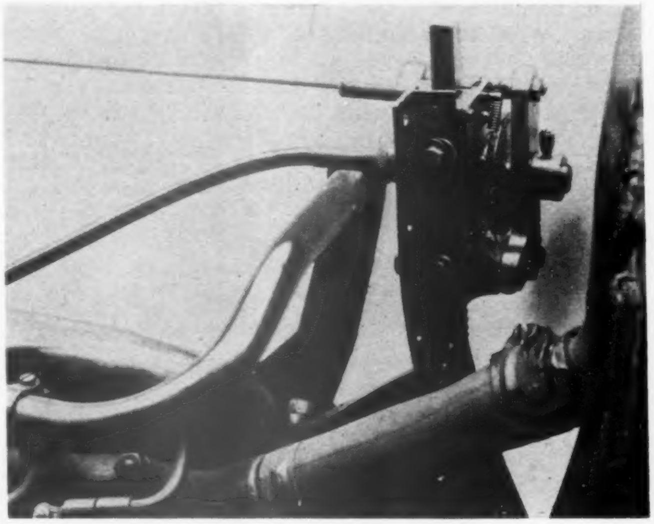

FIG. 5.—THE RACK AND BALL CLUTCH MOUNTED ON AN AUTOMOBILE

over 6 miles of pavement and readings were taken every half mile. The test was repeated and although the car was driven in the same direction over exactly the same length of pavement no attempt was made to follow the same wheel path. The readings at the half-mile intervals are plotted as ordinates on the chart. Although there is a wide variation in the roughness of the different half-mile lengths, the readings on the instrument check very well at the various points. The total readings, i. e., the sum of the readings for the 12 half-mile lengths as obtained on the two test runs, check within 2 per cent. These data are representative and were selected so as to present a fair example of the consistency of the instrument.

The effect of the load in the car or of the type and condition of the body springs is of considerably less importance but should receive attention as there is no doubt that they do affect the results obtained. Tire size, type, and inflation pressure are very important and every effort should be made to keep these constant on all tests the results of which are to be compared.

INTERPRETATION OF THE ROUGHNESS FACTOR

The relative roughness of a road surface is indicated by an abstract number which is a measure of the total average accumulated compression of the two front springs of the vehicle in inches per mile. If the counter be set at zero at the beginning of a trip and the instrument is thrown into operation while the automobile traverses 1 mile of road surface, then the reading on the counter as the car completes this 1 mile of travel may be called the roughness factor for that particular mile of surface. Some idea of what a roughness factor of 100, 200, or 300, means may be gained from the observations following which are based on a heavy car driven at a rate of from 30 to 40 miles per hour.

Roughness factor:	Motion of vehicle
Less than 80	No perceptible vibration.
80 to 110	Slight vibration.
110 to 150	Noticeable vibration and slight lurching.
150 to 200	Disagreeable vibration and noticeable lurching.
200 to 300	Disagreeable lurching and somewhat dangerous for light cars at high speeds.

The magnitude of the roughness factor obtained on various types and conditions of road surfaces has been shown to vary somewhat with the auxiliary equipment used with the roughometer.

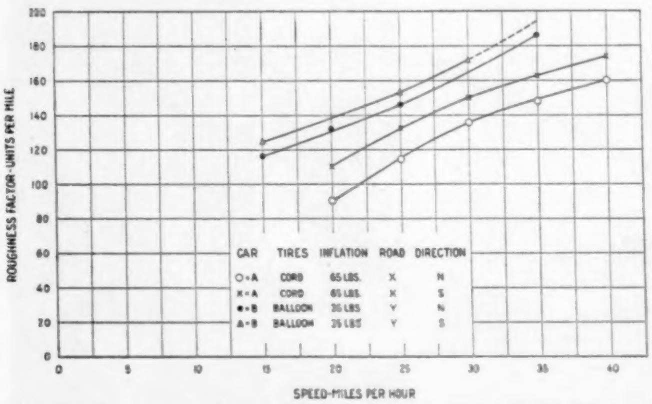

Fig. 6.—Effect of Vehicle Speed on the Roughness Factor as Determined With Two Different Cars, One Equipped With Cord Tires and One Equipped with Balloon Tires

Measurements made in the vicinity of Washington, D. C., indicated a range of from 80 to 100 for very smooth pavements to from 250 to 300 for rather rough surfaces, while some results recently obtained in California with another instrument on another type of automobile range from about 60 for good concrete pavement to 250 for a rather rough oiled gravel.

ROUGHNESS OF DIFFERENT ROADS COMPARED WITH ROUGHOMETER

A brief discussion of some of the data obtained last year by one of the district engineers of the bureau may be of interest. Forty-eight sections of concrete pavement, comprising 412 miles, and five sections of bituminous topped pavement, comprising 59 miles, were measured. The average roughness factors found for particular sections of the two types were, respectively, 141 and 193. The average roughness factor for concrete pavements constructed prior to 1923 is 196, whereas that for those constructed during and since 1923 is 115, showing that very great progress has been made toward constructing smoother pavements.

Data on a section of pavement fairly typical of those constructed six or seven years ago are shown in Table 2, and Table 3 shows similar data for a section constructed in 1924.

Table 2.—*Roughness factors of 5 miles of concrete pavement typical of those constructed prior to 1920*

Mile of pavement	Roughness factor	Mile of pavement	Roughness factor
First	252	Fourth	229
Second	258	Fifth	349
Third	244	Average for 5 miles	266

Table 3.—*Roughness factors of 13 miles of concrete pavement constructed in 1924*

Mile of pavement	Roughness factor	Mile of pavement	Roughness factor
First	90	Ninth	85
Second	90	Tenth	82
Third	81	Eleventh	81
Fourth	84	Twelfth	(hills) 102
Fifth	(hills) 102	Thirteenth	83
Sixth	98		
Seventh	99	Average for 13 miles	89.3
Eighth	84		

In each of three States it was noticed that the first mile constructed was generally the roughest mile in the section. The average roughness factor for the roughest mile in 48 sections in one State was 175 and of the smoothest mile 107, a difference of 68. This difference for 34 sections in another State was 65, and for 13 sections in a third State was 67. This would seem to indicate that very careful supervision should be exercised during the construction of the first mile of pavement laid and that as many first miles should be avoided as possible by awarding contracts early in the season and of such length as may require the entire season to construct. This well illustrates the importance of the roughometer or relative roughness determinator to the highway engineer.

Table 4 presents data which show the greatly increased roughness in the first mile of construction.

Table 4.—*Roughness factors, by miles, on a 7-mile section of pavement, showing increased roughness in the first mile*

Mile of pavement	Roughness factor	Mile of pavement	Roughness factor
First	383	Fifth	115
Second	271	Sixth	126
Third	128	Seventh	156
Fourth	112		

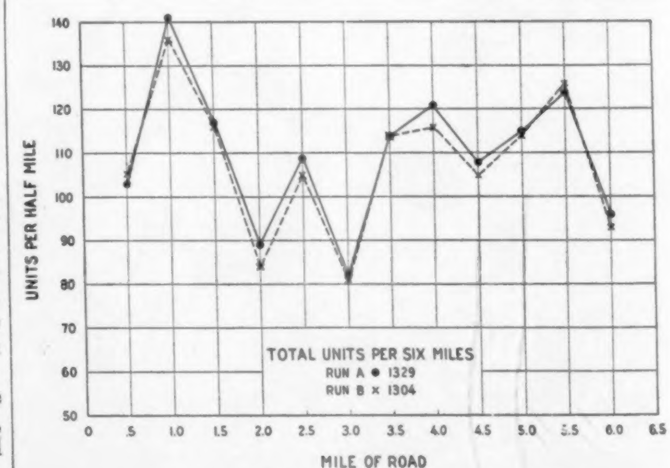

Fig. 7.—Results of Test of Consistency of Instrument in Which Two Runs Were Made in the Same Direction Over the Same Road at a Speed of 20 Miles per Hour. No Attempt was Made to Follow the Same Wheel Path

In general, it has been found that a pavement is smooth or rough all the way across, although in a number of instances a consistent difference between the right and left sides has been observed. Table 5 presents data typical of such a case.

(Continued on p. 151)

THE FLOW OF WATER THROUGH CULVERTS

CONCLUSIONS FROM REPORT ON TESTS AT UNIVERSITY OF IOWA

THE Bureau of Public Roads and the State University of Iowa have recently made a large number of tests of the flow of water through short conduits, such as pipe and box culverts and sluiceways under levees. These tests were conducted at the hydraulic laboratory of the university and have been reported on in Bulletin 1, University of Iowa Studies in Engineering, "The flow of water through culverts," by D. L. Yarnell, drainage engineer, United States Department of Agriculture, in collaboration with Floyd A. Nagler, associate professor of mechanics and hydraulics, and Sherman M. Woodward, professor of mechanics and hydraulics, both of the University of Iowa.

The investigations were undertaken primarily for the purpose of determining—

1. The quantity of water that will flow through culverts or sluiceways under levees of different materials, sizes, and shapes under conditions of actual use.
2. What conditions tend to increase or decrease such quantity.
3. What principles should be followed in design to secure the greatest discharging capacity for the least cost.

The report describes the methods of making the tests and presents the experimental results together with the discharge formulas developed for the various culverts.

The following conclusions are drawn from the results of 1,480 experiments on pipe culverts made of concrete, vitrified clay, and corrugated metal of the following sizes: 12, 18, 24, and 30 inches in diameter; and 1,821 tests on concrete box culverts of the following sizes: 2 by 2 feet, 3 by 3 feet, 4 by 4 feet, 4 by 3 feet, 4 by 2¼ feet, 4 by 2 feet, 4 by 1 foot, and 4 by one-half foot. Tests were made on the culverts flowing partly full and full, both with a free and submerged outlet. Experiments were also run with various types of entrances.

1. The discharging capacity of a culvert depends primarily upon the cross section of the culvert and the difference in water level at the two ends of the culvert.

2. To obtain the maximum discharge the culvert must be so laid as to insure the full cross section of the culvert being filled by the flowing water.

3. If the culvert is laid at too high an elevation with respect to the water levels at the two ends, it will not run full and hence will not attain its maximum capacity.

4. If a culvert is so laid that both its upstream and downstream ends are completely submerged, the amount of water which it discharges will be proportional to the square root of the difference in water level at the two ends; and the exact grade at which the culvert is laid has no effect whatever upon its maximum discharging capacity.

5. The difference in water level at the two ends, called hereafter the head on the culvert, is utilized in three ways—first, in overcoming friction around the entrance corner; second, in overcoming friction along the walls throughout the barrel of the culvert; third, in imparting the velocity necessary to the water in entering the culvert. The three portions into which the total head is thus divided are called for convenience entrance loss, friction loss, and velocity head, respectively.

The following general conclusions numbered from 6 to 25, inclusive, are drawn from the results of the tests on the pipe culverts:

6. The coefficient of roughness, n, in the Kutter formula for the concrete pipe ranges from 0.012 for the 12-inch size to 0.013 for the 30-inch size.

7. The coefficient of roughness, n, in the Kutter formula, for the vitrified-clay pipe ranges from 0.010 for the 12-inch size to 0.013 for the 30-inch size.

8. The coefficient of roughness, n, in the Kutter formula, for the corrugated-metal pipe ranges from 0.019 for the 12-inch size to 0.023 for the 30-inch size.

9. In concrete, vitrified-clay, and corrugated-metal pipe culverts, 30.6 feet long, with straight end-wall entrances:

(*a*) The 12-inch concrete pipe with beveled lip end upstream discharges about 49 per cent more water than the 12-inch metal pipe.

(*b*) The 18-inch concrete pipe with beveled lip end upstream discharges about 40 per cent more water than the 18-inch metal pipe.

(*c*) The 24-inch concrete pipe with beveled lip end upstream discharges about 36 per cent more water than the 24-inch metal pipe.

(*d*) The 30-inch concrete pipe with beveled lip end upstream discharges about 32 per cent more water than the 30-inch metal pipe.

(*e*) The 12-inch clay pipe discharges about 65 per cent more water than the 12-inch metal pipe.

(*f*) The 18-inch clay pipe discharges about 50 per cent more water than the 18-inch metal pipe.

(*g*) The 24-inch clay pipe discharges about 40 per cent more water than the 24-inch metal pipe.

(*h*) The 30-inch clay pipe discharges about 30 per cent more water than the 30-inch metal pipe.

The relative capacities of these culverts may also be expressed in the following terms which are mathematically equivalent to the above.

(*i*) The 12-inch metal pipe has about 67 per cent of the carrying capacity of the 12-inch concrete pipe with beveled lip end upstream.

(*j*) The 18-inch metal pipe has about 71 per cent of the carrying capacity of the 18-inch concrete pipe with beveled lip end upstream.

(*k*) The 24-inch metal pipe has about 74 per cent of the carrying capacity of the 24-inch concrete pipe with beveled lip end upstream.

(*l*) The 30-inch metal pipe has about 76 per cent of the carrying capacity of the 30-inch concrete pipe with beveled lip end upstream.

(*m*) The 12-inch metal pipe has about 61 per cent of the carrying capacity of the 12-inch clay pipe.

(*n*) The 18-inch metal pipe has about 68 per cent of the carrying capacity of the 18-inch clay pipe.

(*o*) The 24-inch metal pipe has about 73 per cent of the carrying capacity of the 24-inch clay pipe.

(*p*) The 30-inch metal pipe has about 78 per cent of the carrying capacity of the 30-inch clay pipe.

10. In concrete pipe culverts, 30.6 feet long, with straight end-wall entrances:

(*a*) The 12-inch pipe with beveled lip end upstream discharges about 5 per cent more water than the same pipe with a square-cornered entrance.

(*b*) The 18-inch pipe with beveled lip end upstream discharges about 9 per cent more water than the same pipe with a square-cornered entrance.

(*c*) The 24-inch pipe with beveled lip end upstream discharges about 12 per cent more water than the same pipe with a square-cornered entrance.

(*d*) The 30-inch pipe with beveled lip end upstream discharges about 14 per cent more water than the same pipe with a square-cornered entrance.

11. Due to the larger amount of pipe friction in corrugated-metal pipes, a change in culvert length produces a greater change in discharge than with concrete and vitrified-clay pipe culverts.

12. The 45-degree wing walls used in connection with a corrugated-metal pipe culvert increase the capacity from 1 to 10 per cent over that obtained in a metal pipe culvert with a straight end wall.

MOTOR VEHICLE REGISTRATIONS FOR THE FIRST SIX MONTHS OF 1926[1]

States	Registered motor vehicles individually and commercially owned [2]			Special list of passenger cars for hire [3]		Other registered vehicles [4]		Tax-exempt official motor vehicles and motor cycles [5]			Number of licenses or permits (automobile)			Grand total registered motor cars and trucks first six months of 1925	Per cent increase 1926 over 1925	States
	Grand total registered motor cars and trucks 1926	Passenger automobiles, taxis, and busses [6]	Motor trucks and road tractors [6]	2 to 7 passenger capacity	Over 7 passenger capacity	Trailers	Motor cycles	United States cars [7]	State and local cars	Motor cycles (official)	Dealers	Operators	Chauffeurs			
Alabama	197,602	173,383	24,219	2,163	76	740	313	167			387		1,604	182,561	8.2	Alabama.
Arizona	64,165	56,312	7,853	371	95		295	176	656		212		104	59,809	7.3	Arizona.
Arkansas	177,235	152,537	24,698	1,917	167	1,150	193	39	542	34	472		4,141	148,981	19.0	Arkansas.
California	1,459,570	1,262,841	[6] 196,729	4,765	1,842	26,353	8,968	1,217	18,716	360	2,939		88,355	1,317,825	10.8	California.
Colorado	225,810	208,648	17,162	1,361	426		1,168	283			3,128			213,891	5.6	Colorado.
Connecticut	238,727	201,253	37,474	1,874	465	256	2,718	71	1,059	168	349	255,719	3,205	216,746	10.1	Connecticut.
Delaware	40,303	32,625	[6] 7,678	190	49	150	360	44			595	40,875	3,625	35,600	13.2	Delaware.
Florida	407,777	343,349	[6] 64,428	2,423	522		1,146	75	2,265	161	3,106		8,848	231,439	76.2	Florida.
Georgia	238,618	208,602	30,016	1,664	161		678	934			806		2,856	207,663	14.9	Georgia.
Idaho	84,161	77,276	6,885	359	57	153	411	103	1,077	21	386		303	73,500	14.5	Idaho.
Illinois	1,217,265	1,062,844	154,421	10,033	1,250	2,537	4,627	979			4,392		80,856	1,123,084	8.4	Illinois.
Indiana	690,704	598,338	92,366	3,648	1,177	4,521	2,865	3,184	3,308		2,307		32,400	659,782	4.7	Indiana.
Iowa	648,282	601,011	47,271	1,999	259		1,739	44	2,500	79	2,205		9,462	611,002	6.1	Iowa.
Kansas	433,561	390,951	[6] 42,610	1,690	274		988	192	2,084	51	2,371			406,990	6.5	Kansas.
Kentucky	247,104	222,487	24,617	2,918	347		517	90	1,300	49	1,098		7,616	233,828	5.7	Kentucky.
Louisiana	216,500	183,000	33,500	970	261		390	209						190,896	13.4	Louisiana.
Maine	128,466	108,625	19,841	1,977	186	604	801	64	992	68	1,140	150,027	5,104	126,200	1.8	Maine.
Maryland	227,491	216,634	10,857	2,266	581	518	3,255	1,969			5,441	18,268	12,813	208,338	9.2	Maryland.
Massachusetts	627,736	537,761	89,975	6,002	1,354	436	6,746	556			2,019	404,370		576,103	9.0	Massachusetts.
Michigan	992,178	862,916	[6] 129,262	3,153	1,703	10,093	2,835	371	5,975		2,025	110,041	63,009	798,460	24.3	Michigan.
Minnesota	574,356	512,163	62,193	1,616	605	2,161	2,320	252	213		2,103			519,168	10.6	Minnesota.
Mississippi	180,030	161,519	18,511	1,114	144	3,000	68	74			5,087			148,758	21.0	Mississippi.
Missouri	583,450	525,333	58,117	4,528	664	1,402	1,501	311	1,305	13	2,159	4,435	20,855	535,528	8.9	Missouri.
Montana	92,340	79,608	[6] 12,732	526	117		157	229	971		423		316	83,950	10.0	Montana.
Nebraska	329,669	304,922	[6] 24,747	1,150	87	926	926	226			2,409			295,341	11.6	Nebraska.
Nevada	20,527	16,480	4,047	119	12	39	66	42	373	6	110			17,939	14.4	Nevada.
New Hampshire	78,979	70,291	8,688	1,757	144	436	1,107	22	650		474	56,000	30,000	73,120	8.0	New Hampshire.
New Jersey	575,237	467,385	107,852	5,158	2,807	1,365	5,819	708	5,031	775	2,501	654,305		505,474	13.8	New Jersey.
New Mexico	46,571	44,894	1,677	346	54	107	151	156		4	130			42,205	10.3	New Mexico.
New York	1,562,492	1,302,359	260,133	31,892	3,113	4,964	15,152	1,666	10,847		4,221	1,182,902	393,050	1,404,653	11.2	New York.
North Carolina [1]	371,353	338,192	33,161	1,871	254	500	1,057	429	4,443		761			[1] 315,000	10.8	North Carolina.
North Dakota	144,079	134,331	9,748	292	28		241	3	122					126,106	14.3	North Dakota.
Ohio	1,370,756	1,219,202	151,554	4,811	1,717	8,784	7,117	2,362	7,150	258	3,652		3,756	1,292,000	6.1	Ohio.
Oklahoma	490,000	445,000	45,000	1,886	271		732	530			2,300			420,000	16.7	Oklahoma.
Oregon	195,641	181,211	[10] 14,430	686	357	([10])	1,788	141			561	22,845	10,946	179,566	9.0	Oregon.
Pennsylvania	1,326,682	1,143,932	182,750	6,455	1,837	2,852	11,003	1,383	3,018	867	26,216	1,372,753		1,205,287	10.1	Pennsylvania.
Rhode Island	96,652	80,163	16,489	1,282	191	57	1,014	56	540	68	263	64,540		89,247	8.3	Rhode Island.
South Carolina	151,012	137,397	13,615	1,060	80	778	142	91			480		77	141,208	6.9	South Carolina.
South Dakota	155,763	142,680	13,083	319	57		192	85	802		1,027			150,335	3.6	South Dakota.
Tennessee	227,775	207,894	19,881	1,972	219		503	132	2,066	60	506			218,735	4.1	Tennessee.
Texas	904,050	820,476	83,574	5,130	531	4,745	1,980	2,505			2,877		8,466	848,661	6.5	Texas.
Utah	81,830	70,877	10,953	322	94	402	482	173	705		281		2,269	76,410	7.1	Utah.
Vermont	62,899	58,168	4,731	715	102	81	464	28			341	56,532	12,428	60,424	4.1	Vermont.
Virginia	277,125	241,500	35,625	1,816	548	420	1,599	1,141	2,551	226	3,605		6,704	261,400	6.0	Virginia.
Washington	326,500	280,776	45,724	1,044	483	1,341	2,106	637	4,028	142	1,200			293,589	11.2	Washington.
West Virginia	183,788	162,530	21,258	1,276	153	245	962	33	1,739		11,127	35,390	21,050	184,200	([11])	West Virginia.
Wisconsin	590,797	520,134	70,663	2,568	591		2,433	92	300	63	2,693			534,662	10.5	Wisconsin.
Wyoming	44,367	39,608	4,759	286	321		149	209	205		275			42,600	4.1	Wyoming.
District of Columbia	89,857	78,356	11,501	995	247		1,186	837	1,801	181	1,794	5,973		82,427	9.0	District of Columbia.
Grand total	19,697,832	17,288,774	2,409,058	134,735	27,080	82,116	103,436	[12] 33,179	89,334	3,654	114,954	4,434,975	834,218	[8] 17,770,691	10.8	Grand total.

[1] All States but North Carolina report details for first six months, 1926. North Carolina has registration year ending June 30, which full year is reported here.

[2] The first three columns record the regularly registered motor cars and trucks excluding where possible nonresident registrations and reregistrations. The grand total registration in the first column is subdivided into passenger-carrying cars shown in the second column, and motor trucks and road tractors shown in the third column.

[3] Special list showing passenger cars for hire on which there was paid internal revenue tax during fiscal year ending June 30, 1926. These vehicles are included in the grand total as a result of their regular registration.

[4] Shows the registered trailers; some States do not register trailers, or they are included with motor trucks. The registered motor cycles with or without side cars are shown. Both classes here listed are not included in grand total.

[5] Shows motor vehicles and motor cycles which are tax-exempt and owned by United States Government, States, counties, and municipalities, etc. These vehicles are not included in grand total registration.

[6] Busses reported with trucks in several States as noted in third column.

[7] Data obtained from United States Government sources as of June 30, 1925.

[8] Corrected figure—previously published figure included reregistrations.

[9] Includes about 7,800 cars owned by public-service corporations, not taxed by law.

[10] Oregon includes trailers with motor trucks

[11] Slight decrease due to delay in registrations caused by new law on title certificates.

[12] Includes 7,859 "cars at large" not allocated to any State.

RECEIPTS FROM MOTOR VEHICLE FEES, ETC., FOR THE FIRST SIX MONTHS OF 1926

States[2]	Total gross receipts	Subdivision of registration receipts[1]					Miscellaneous receipts[1]			Disposition of gross receipts					States
		Motor cars			Other vehicles						For highway purposes				
		Total motor cars	Passenger cars and busses	Trucks and tractors	Trailers	Motor cycles	Dealer's licenses	Chauffeur and operator permits	Miscellaneous	Collection and administration	State highways	Local roads	State and county road bonds[9]	For other purposes	
Alabama	$2,638,532									[3] $92,265	$2,031,753	$514,514			Alabama.
Arizona	389,620										389,620				Arizona.
Arkansas*	3,793,915	$3,668,825	$3,074,965	$593,860	$17,250	$1,995	$47,200	$20,705	$37,940	13,000	1,780,915	802,198	c$1,197,802		Arkansas.
California*	7,163,610	6,677,047	4,139,074	2,537,973	221,393	31,650	28,811	181,974	22,735	1,432,722	2,865,444	2,865,444			California.
Colorado*	1,389,008	1,315,924	1,107,921	208,003		2,336	70,748			69,450		659,779	c659,779		Colorado.
Connecticut*	5,587,387	4,473,897	3,446,691	1,027,206	7,306	11,091	17,241	783,182	294,670		5,587,387				Connecticut.
Delaware*	702,739	544,914	392,864	152,050	2,512	1,440	6,820	133,203	13,850		702,739				Delaware.
Florida	5,513,054									275,653	3,859,138	1,378,263			Florida.
Georgia*	3,101,444	3,048,980	2,543,575	505,405		3,383	40,300	5,709	3,072	84,503	3,016,941				Georgia.
Idaho*	1,266,811	1,235,648	1,049,513	186,135	3,745	2,055	21,940	606	2,817		114,013	1,140,130	12,668		Idaho.
Illinois*	13,049,809	12,357,343	9,416,020	2,941,323	53,285	17,468	87,802	284,065	249,846		7,539,809		5,510,000		Illinois.
Indiana*	4,672,329	4,427,564	3,448,325	979,239	24,378	5,724	46,100	32,453	136,110		4,672,329				Indiana.
Iowa	9,672,121									338,524	9,333,597				Iowa.
Kansas	5,202,732									218,473	3,738,194	1,246,065			Kansas.
Kentucky*	3,830,636	3,745,719	2,883,295	862,424		4,354	31,116	14,740	34,707	52,198	3,372,226	406,212			Kentucky.
Louisiana	3,549,857									75,429	3,474,428				Louisiana.
Maine*	2,021,667	1,585,304	1,272,247	313,057	2,191	4,885	42,860	324,237	62,190	84,203	1,612,898		324,566		Maine.
Maryland*	2,337,334	2,073,546	1,807,892	265,654	13,411	12,366	28,236	94,946	114,829	188,284	1,719,240	[4] 429,810			Maryland.
Massachusetts*	10,859,151	9,698,037	6,454,442	3,243,595	19,181	34,074	60,555	808,740	238,564	696,272	8,078,643	925,187	1,159,049		Massachusetts.
Michigan*	14,955,637	13,982,313	10,515,682	3,466,631	155,514	11,220	105,561	181,038	519,991	251,345	7,504,292	6,000,000	1,200,000		Michigan.
Minnesota*	9,238,683	9,165,327	7,555,186	1,610,141	11,930	9,133	37,467	7,849	6,977		5,469,683		c3,769,000		Minnesota.
Mississippi*	1,600,000	1,530,785	1,372,441	158,344	25,500	476	43,239			48,000		1,552,000			Mississippi.
Missouri	6,885,456									238,755	2,611,166		4,035,535		Missouri.
Montana*	1,029,383	895,605	751,875	143,730		1,178	33,825	626	98,149	26,670		989,595		[5] 13,118	Montana.
Nebraska*	3,326,374	3,243,890	2,782,662	461,228	3,287	3,215	36,743		39,239	83,159	972,965	2,270,250			Nebraska.
Nevada	188,585										108,585		80,000		Nevada.
New Hampshire	933,157	741,788				6,343	7,030	144,664	33,332	87,542	845,615				New Hampshire.
New Jersey*	10,437,134	7,889,584	4,724,846	3,164,738	49,945	11,638	62,780	1,962,915	460,272	239,315	6,020,319	4,140,000		[6] 37,500	New Jersey.
New Mexico*	379,391	359,931	291,623	68,308	2,327	504	6,688		9,941	32,108	231,522	115,761			New Mexico.
New York*	26,082,449	24,056,668	16,820,010	7,236,658	53,570	65,568	153,427	1,585,586	167,630	1,187,386	18,671,298	6,223,765			New York.
North Carolina[1]	8,630,754									300,000	8,330,754				North Carolina.
North Dakota*	1,421,338	1,400,594	1,247,112	153,482		1,201			19,543	150,000	570,669	570,669		[7] 130,000	North Dakota.
Ohio	8,516,811	8,308,430					73,040	10,133	125,208		4,326,076	4,190,735			Ohio.
Oklahoma	4,996,420									39,215	1,959,353	2,997,852			Oklahoma.
Oregon*	5,469,761	5,349,179	4,591,136	758,043		11,283	28,000	44,737	36,562		4,102,321	1,367,440			Oregon.
Pennsylvania*	21,208,912	17,471,798	12,014,666	5,457,132	32,888	32,659	315,288	1,371,744	1,984,535	1,102,837	19,914,604			[8] 191,471	Pennsylvania.
Rhode Island*	1,680,595	1,483,744	1,090,499	393,245	662	4,031	13,990	129,080	49,088	79,057	1,601,538				Rhode Island.
South Carolina*	1,782,898	1,705,680	1,451,138	254,542	14,274	927	22,315		39,702	135,917	1,646,981				South Carolina.
South Dakota*	2,399,567	2,372,732	2,104,530	268,202		960	25,675		200	47,991	1,199,784	1,151,792			South Dakota.
Tennessee*	3,166,140	3,143,813	2,369,991	773,822		2,087	20,240			39,795	3,126,345				Tennessee.
Texas	13,046,170	12,777,253				8,755	54,221	24,786	181,155		9,429,278	3,616,892			Texas.
Utah*	576,803	552,841	439,269	113,572	2,230	1,086	12,393	3,993	4,260				576,803		Utah.
Vermont*	1,502,226	1,308,306	1,128,117	180,189	486	3,611	26,298	163,525			1,502,226				Vermont.
Virginia*	4,129,297	3,834,186	3,239,714	594,472	3,780	5,780	53,398	27,961	204,192	148,132	3,981,165				Virginia.
Washington*	5,229,759	5,092,999	3,988,395	1,104,604	34,325	12,470	85,741		4,224	182,097	4,179,142	868,520			Washington.
West Virginia*	3,254,262	2,944,126	2,473,682	470,444	2,091	4,173	49,649	98,269	155,954	240,921	1,112,756		1,900,585		West Virginia.
Wisconsin*	8,281,602	7,965,569	6,621,587	1,343,982		15,839	67,365		232,829	321,268	5,995,334	1,965,000			Wisconsin.
Wyoming*	441,035	433,364	348,500	84,864		745	6,875		51				441,035		Wyoming.
Dist. of Col.*	246,794	97,346	78,356	18,990		1,186	1,794	10,416	136,052	18,410	228,384				Dist. of Col.
Detailed total[2]	187,615,880	171,133,128	129,037,841	42,095,287	757,461	333,791	1,738,480	8,272,299	5,380,721						Detailed total.
Grand total	257,779,149									8,620,896	179,531,469	48,387,873	[9] 20,866,822	372,089	Grand total.

[1] All States report data covering first 6 months except North Carolina, which shows full fiscal year ending June 30, 1926.
[2] Only the 36 states starred (*) in the first column reported complete receipt details which are totaled under first 9 receipt columns, shown as "detailed total."
[3] Includes $65,963 for probate judges.
[4] For Baltimore streets.
[5] For auto theft law enforcement.
[6] For toll bridge commission.
[7] Allocated to bridge fund.
[8] For State highway motor patrol.
[9] County bond payments shown above by prefix "c"

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

STATUS OF FEDERAL AID HIGHWAY CONSTRUCTION

AS OF

AUGUST 31, 1926

STATES	FISCAL YEARS 1917-1926			FISCAL YEAR 1927									BALANCE OF FEDERAL AID FUND AVAILABLE FOR NEW PROJECTS	STATES
	PROJECTS COMPLETED PRIOR TO JULY 1, 1926			PROJECTS COMPLETED SINCE JUNE 30, 1926			*PROJECTS UNDER CONSTRUCTION			PROJECTS APPROVED FOR CONSTRUCTION				
	TOTAL COST	FEDERAL AID	MILES	TOTAL COST	FEDERAL AID	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES		
Alabama	$ 18,226,411.34	$ 8,725,985.09	1898.3	$ 1,033,298.73	$ 492,916.35	75.7	$ 4,036,643.28	$ 1,865,385.81	131.4	$ 307,154.54	$ 153,577.27	19.9	$ 3,111,590.48	Alabama
Arizona	10,943,878.25	5,863,772.35	729.8	272,263.37	172,004.74	26.7	1,365,684.79	944,542.22	68.8	82,189.48	50,225.99	12.2	2,586,703.70	Arizona
Arkansas	18,364,544.50	7,666,699.35	1323.0	362,027.07	179,003.72	26.7	4,364,161.43	2,065,766.25	282.0	897,052.81	443,831.94	87.9	1,250,503.74	Arkansas
California	27,142,596.90	13,003,592.30	1058.0	145,035.87	67,021.52	11.5	12,159,380.20	5,922,687.78	321.3	717,759.37	416,237.89	12.3	2,643,275.51	California
Colorado	13,906,904.64	7,127,288.18	745.0	439,800.74	236,115.35	8.2	4,716,491.19	2,279,078.52	230.0	500,176.37	276,344.35	35.1	2,406,985.61	Colorado
Connecticut	5,414,567.19	2,100,585.80	117.1				4,140,337.20	1,087,698.03	59.2	589,473.04	259,391.25	4.2	886,006.92	Connecticut
Delaware	4,918,052.29	1,781,665.60	124.3				1,115,536.81	470,577.90	28.2	623,535.35	218,310.90	15.7	3,503.60	Delaware
Florida	3,632,680.26	1,824,362.32	132.9	982,922.96	489,063.29	31.9	8,702,382.31	4,034,437.89	247.9	241,489.11	119,798.25		1,617,292.56	Florida
Georgia	24,791,206.97	11,664,237.86	1794.0	710,862.99	349,830.77	39.4	12,133,040.41	5,953,775.80	625.7	827,784.58	356,571.17	20.2	107,537.40	Georgia
Idaho	11,061,199.14	5,882,112.70	724.7	295,719.53	149,898.93	7.8	2,963,163.97	1,800,754.40	177.8	792,108.22	469,819.38	71.5	267,041.89	Idaho
Illinois	44,116,611.86	20,619,995.74	1377.7	2,012,307.84	990,960.66	68.1	7,501,516.63	3,627,458.88	263.3	657,378.09	302,879.03	21.0	4,300,903.69	Illinois
Indiana	16,949,425.87	8,172,126.19	534.3	1,692,937.11	791,062.95	47.8	17,579,418.96	8,289,152.68	505.6	281,117.68	140,558.84	7.2	811,455.34	Indiana
Iowa	29,062,375.40	11,926,302.10	2114.8	378,793.37	186,807.05	25.6	11,918,971.28	5,737,713.15	733.1	2,930,081.42	1,326,566.32	119.0	308,074.38	Iowa
Kansas	32,826,601.64	12,690,489.25	1160.6	455,951.75	202,404.07	39.6	12,379,069.79	4,824,178.50	666.9	2,715,366.74	1,009,919.23	144.5	837,419.95	Kansas
Kentucky	20,737,706.10	8,492,082.26	758.3	207,209.39	106,386.83	6.3	6,684,243.21	3,219,303.43	336.4	560,491.27	279,745.62	83.6	1,115,290.87	Kentucky
Louisiana	13,830,592.68	6,144,739.99	1055.9				3,497,782.62	1,697,567.74	161.3	1,346,845.99	619,114.94	47.3	810,985.33	Louisiana
Maine	8,747,552.76	4,192,807.39	303.6				2,364,417.18	854,849.24	67.3	1,456,698.19	610,367.98	50.2	807,103.39	Maine
Maryland	10,924,943.10	5,112,991.22	423.3				513,398.28	252,643.43	30.8	1,263,113.28	569,420.86	57.7	1.49	Maryland
Massachusetts	18,353,757.71	6,657,260.62	374.5	58,723.21	22,710.05	0.2	4,807,818.26	1,284,622.27	66.1	1,174,386.11	311,928.56	19.0	1,832,204.51	Massachusetts
Michigan	25,997,240.78	11,827,052.30	963.0	390,946.77	188,717.04	13.6	11,635,732.67	5,332,933.17	318.1	1,034,498.96	440,238.19	23.6	2,553,424.30	Michigan
Minnesota	37,170,985.95	15,586,116.56	3181.9	1,771,684.13	821,789.07	204.0	8,004,732.22	3,003,100.00	387.2	477,555.12	36,000.00	16.1	144,604.37	Minnesota
Mississippi	15,146,088.52	7,414,534.10	1129.0	593,316.41	294,031.56	36.8	6,865,002.79	3,401,331.84	379.0	1,321,827.50	592,714.92	49.1	425,405.58	Mississippi
Missouri	28,989,166.92	13,736,014.85	1543.2	2,937,837.45	1,263,067.36	78.8	18,107,810.63	7,230,468.54	505.5	460,972.41	202,106.41	7.5	354,778.84	Missouri
Montana	11,400,983.81	6,333,465.89	1064.9	286,140.87	134,452.39	31.9	2,360,606.34	1,056,271.18	160.7	982,999.25	580,430.98	112.2	4,520,264.56	Montana
Nebraska	11,533,401.62	5,474,202.52	1768.3	416,979.92	206,210.54	42.2	13,456,039.51	6,644,568.45	1397.9	868,508.28	410,550.09	121.2	1,899,703.40	Nebraska
Nevada	7,558,195.51	5,130,934.59	538.8	1,219,911.65	1,062,768.79	116.0	2,214,266.87	1,894,315.49	274.1	41,715.60	36,592.91		670,603.22	Nevada
New Hampshire	4,992,558.60	2,377,460.07	237.6				1,339,869.53	601,785.70	39.3	38,717.88	29,092.93	0.1	161,163.30	New Hampshire
New Jersey	16,346,301.01	5,098,342.21	290.3	156,206.43	63,465.76	4.0	8,295,562.92	2,763,486.67	48.1	1,441,354.16	289,789.17	18.1	252,316.19	New Jersey
New Mexico	12,404,337.77	7,339,657.38	1427.0				1,883,157.63	1,241,284.96	183.0	552,060.38	413,314.99	66.0	1,978,128.67	New Mexico
New York	43,224,279.79	17,911,957.19	1197.0	1,875,003.91	676,396.18	42.0	38,030,973.00	9,446,955.20	597.2	8,723,050.00	1,900,000.00	118.0	4,109,886.43	New York
North Carolina	27,009,419.47	11,177,337.94	1257.9	3,621,683.44	1,412,891.77	73.3	4,970,040.28	2,268,851.50	132.6	972,106.70	456,189.10	40.5	401,935.69	North Carolina
North Dakota	12,313,311.40	6,031,859.78	2193.1	165,795.69	82,897.68	22.2	7,747,244.18	4,044,457.00	979.1	1,141,361.65	587,665.63	178.2	1,778.91	North Dakota
Ohio	47,699,532.90	17,371,787.03	1364.1	1,029,433.36	464,851.87	40.7	12,181,657.75	4,672,653.58	353.8	3,438,761.00	1,178,882.13	96.1	2,043,621.39	Ohio
Oklahoma	28,247,950.33	13,159,999.15	1178.9	426,315.32	212,294.12	19.6	2,613,646.38	1,215,306.60	101.8	1,285,313.86	606,754.67	96.7	865,432.46	Oklahoma
Oregon	17,027,878.42	8,593,214.79	939.2	387,712.64	201,299.62	22.0	3,238,079.35	1,770,139.62	113.2	238,968.69	143,381.21	13.3	171,311.76	Oregon
Pennsylvania	61,366,150.80	21,560,732.04	1188.6				27,087,825.96	7,711,872.53	550.1	2,407,226.26	731,213.01	47.6	1,334,963.42	Pennsylvania
Rhode Island	3,988,616.09	1,558,829.06	86.7	207,117.54	86,175.00	5.7	1,282,981.70	340,980.00	22.7	743,891.14	201,195.00	13.4	480,389.94	Rhode Island
South Carolina	15,020,639.90	6,766,322.93	1481.9	698,097.01	247,788.28	38.1	5,914,916.16	2,726,699.15	204.4	155,548.99	50,921.58	19.9	9,792.06	South Carolina
South Dakota	17,469,373.19	8,603,826.97	2181.2	285,742.04	142,871.01	78.7	3,843,913.49	1,936,835.85	639.1	596,224.95	313,144.19	99.6	170,111.98	South Dakota
Tennessee	21,624,631.57	10,276,584.02	760.0	51,931.02	27,983.60	0.9	8,873,923.60	3,952,348.28	253.1	739,242.79	328,777.17	19.0	694,897.93	Tennessee
Texas	69,183,673.48	27,440,254.79	4820.2	631,891.52	288,965.47	48.3	18,511,186.40	8,182,775.90	864.2	2,477,214.12	1,130,036.92	61.5	3,584,397.99	Texas
Utah	8,253,178.03	5,098,440.68	546.4	72,006.59	53,284.87	9.1	1,760,452.52	1,330,318.86	158.1	864,739.48	658,542.65	53.5	678,191.94	Utah
Vermont	4,242,042.64	2,017,699.51	134.5				2,098,553.60	812,423.54	39.0	51,449.37	13,905.01	0.8	424,478.94	Vermont
Virginia	21,990,249.44	10,385,728.11	1005.5	517,237.89	238,128.61	14.9	6,431,746.40	2,750,981.14	186.4	138,973.67	68,172.20	2.6	58,503.94	Virginia
Washington	17,078,511.63	7,782,909.46	668.6	267,789.25	101,642.49	4.3	3,294,245.95	1,630,600.00	43.5	1,008,163.90	374,000.00	43.7	256,624.05	Washington
West Virginia	9,473,716.44	4,141,062.65	392.9	457,126.16	193,696.41	12.5	4,805,344.41	1,869,689.67	124.7	1,594,741.81	709,692.13	62.8	438,370.14	West Virginia
Wisconsin	24,856,508.19	10,392,705.73	1592.1	101,729.42	50,664.71	9.3	8,154,614.98	3,927,945.62	376.2	742,702.15	339,241.00	25.2	2,728,257.94	Wisconsin
Wyoming	10,928,302.56	6,040,887.05	1133.5	341,141.32	218,189.00	47.9	2,842,290.94	1,795,908.53	213.8	112,844.59	84,159.81	24.3	427,129.61	Wyoming
Hawaii							1,060,897.93	312,635.18	15.9				787,517.82	Hawaii
TOTALS	966,692,834.36	426,178,703.58	52,526.6	27,978,021.28	13,160,699.40	1,431.3	358,840,753.79	152,882,117.36	14,604.9	52,606,936.28	20,821,413.75	2,189.1	58,332,065.83	TOTALS

* Includes projects reported completed (final vouchers not yet paid) totaling: Estimated cost $ 89,526,921.22 Federal aid $ 38,486,599.58 Miles 3,457.4